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RHEOLOGICAL EVALUATION OF EMULSIFIED JP-4 FUEL

By

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June 1968

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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THIOKOL CHEMICAL CORPORATION
REACTION MOTORS DIVISION
DENVILLE, NEW JERSEY

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This report was prepared by Thiokol Chemical Corporation, Reaction Motors Division, Denville, New Jersey, under the terms of Contract DAAJ02-67-C-0104. It reports the results of a series of measurements of some of the rheological properties of an emulsified fuel which was developed by Monsanto Research Corporation under the terms of Contract DA 44-177-AMC-445(T). The following properties were investigated: the variation of yield stress with age, temperature, and condition of the emulsion; the droplet size distribution in the emulsion as it is affected by the condition of the emulsion; and the drop size distribution of typical gas turbine fuel nozzles.

Conclusions and recommendations contained herein are concurred in by this Command.

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RHEOLOGICAL EVALUATION OF EMULSIFIED JP-4 FUEL

Final Report

Report RMD 5127-F

By

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Prepared by

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for

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS VIRGINIA

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SUMMARY

A study has been made to characterize an emulsified JP-4 fuel which, if proved operational for jet engines, can greatly increase aircraft safety. The study includes the measurement of the rheological properties, namely, yield point and apparent viscosity, over a range of temperatures and as a function of mixing time and aging. The droplet diameter of the fuel before and after alteration (by additional mixing) and after aging was also established.

The results show that both the yield point and the apparent viscosity of the emulsion increase with decreasing temperature. The emulsion, if mixed for 2 to 5 minutes in a dough type mixer, will increase in yield point. However, there appears to be very little difference in the droplet diameter of batches having different yield points. In addition, the droplet diameter does not appear to be affected by aging.

The pressure drop across a 20-foot length of 1-inch line was measured, and the spray pattern developed after flowing through a helicopter nozzle was analyzed. The pressure drop was unaffected by the rheology of the emulsion, but the spray pattern through the fine orifice nozzles was adversely affected. Liquid JP-4 formed a stable fine-mist spray, while the emulsion formed a spray which ranged from good atomization to almost no atomization.

It was concluded from the above studies that the emulsion can be used over a wide temperature range (-10° to 140°F), but it must be broken down to a liquid form before efficient atomization can be achieved.

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INTRODUCTION

The additional hazards associated with the crash of an aircraft are caused by the mobility and easy ignitability of the fuel. The rupture of the fuel tanks will allow the fuel to spill over a large area and, if ignited, will engulf the aircraft in flames. An approach which has been under intensive investigation to reduce this hazard is to use the fuel in an emulsified state. Since the emulsion is a thickened mass, its mobility is decreased by a considerable amount; however, for the emulsion to be useful, it must be sufficiently stable to be stored in tankage for prescribed periods of time, it must not undergo any change in properties which is detrimental to its pumpability, and it must atomize efficiently when fed into the engine.

In view of the crucial nature of the application, it is imperative to know and understand the characteristics of the emulsion. It has been the purpose of this program to characterize and evaluate one of the emulsions under consideration for aircraft use. The object of this characterization is to define experimental parameters such as yield stress, viscosity, droplet size, pressure drop, and nozzle spray patterns which will aid in the evaluation of the emulsion for acceptance for use in a full-scale engine.

EXPERIMENTAL TESTING

MATERIAL

The fuels for the experiments, which were provided by the Government, consisted of the following:

Liquid JP-4	100 gallons
Emulsified JP-4	300 gallons

The emulsified fuel was prepared by Thiokol Corporation, Brunswick, Georgia, according to the Monsanto Formula, which is as follows:

97.0 V/O JP-4

1.3 V/O H_2O

1.7 V/O Emulsifying Agent and other

PROCEDURES

Droplet Size Determination

Internal Phase Droplet Size

1. Optical Equipment - The droplets of the internal phase of the emulsified JP-4 fuel were examined microscopically by using a Bausch and Lomb LC Petrographic microscope. Photomicrographs of the droplets were obtained by using a Polaroid MP-3 Industrial View Land Camera (equipped with a special lensless shutter and light baffle tube) fitted to the microscope.

2. Slide Preparation - The sample materials were placed on clean microscope slides. Thin smears were then made, and cover glasses were placed over the samples.

3. Photographing and Counting Procedures - After the slides were examined and the internal phase droplets were identified, random fields of view were

photographed. The micrometer scale in the eyepiece was calibrated so that in the resulting Polaroid pictures each small division represented 2.1 microns at 900X magnification. The diameters of the internal phase droplets on the picture were measured and counted. Because of limitation of the optical microscope, the smallest diameter that could be resolved was 0.25 micron; in general, the accuracy of the measurement was better than ±0.2 micron throughout the study.

4. Internal Phase Droplet Diameter Analysis - A digital computer program was written for the IBM 360 Model 50 computer using the FORTRAN-IV language. The program was employed for the statistical analysis of the internal phase droplet size distribution.

Nozzle Spray Droplet Size

Propellant droplet patterns and sizes were obtained by using silhouette photographs of the spray taken with a camera with an open shutter and a flash illumination of about 2 microseconds and a General Radio Corporation Type 1533-A high-speed stroboscope with two lights. The arrangement of the lights is shown in Figure 1.

The photographs obtained were magnified by projecting them on a screen, where the drops were measured. The size distribution is obtained by measuring the size of each droplet within a particular section of the spray. The size distribution thus obtained will be a spatial one, as opposed to a temporal distribution. This technique is similar to one used by York and Stubbs.* The smallest particle which can be resolved with the lens used is in the 20- to 30-micron range. The distribution is computed by the technique described above.

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*York, J. L., and Stubbs, H. F., PHOTOGRAPHIC ANALYSIS OF SPRAYS, Trans ASME, 74, 1157 (1952).

Emulsified JP-4 Fuel Alteration

The emulsified JP-4 fuel was altered (increase of yield point) by mixing 1-gallon quantities for a given period of time in a Hobart Mixer, Model C-100. The mixer was operated at the high-speed setting, using large, flat blades.

Rheology

Yield Point

Yield point was measured by using the Rising Sphere method. The instrument consists of a steel sphere (2.063 cm diameter) attached by a length of thin steel wire to a load cell. The emulsion sample is contained in a controlled temperature cabinet which rests on a horizontal cross arm, which can be raised or lowered at controlled speeds. The load cell and cross arm are part of an Instron Model TT-C testing instrument. The sphere is placed in the lower third of the sample, and the cross arm is lowered at a constant speed (8.5×10^{-4} cm/sec). The resulting force on the load cell versus time is recorded until the force reaches a constant value. The yield stress value is then calculated by using the equation

$$\text{Yield Stress} = \frac{(F - WS)\,g}{4\,\pi\,r^2}$$

where F = maximum recorded force, gm

WS = weight of sphere in emulsion (wt in air less wt of emulsion displaced by sphere), gm

g = gravitational acceleration constant, cm/sec^2

r = radius of the sphere, cm

Shear Stress-Shear Rate Relationship

The shear stress-shear rate relationship of emulsified JP-4 fuel was determined by using both the Ferranti-Shirley (cone and plate) and the capillary viscometer. A description of the methods for obtaining the shear stress-shear rate relationships, using these instruments, is given below.

1. Ferranti-Shirley Viscometer - The Ferranti-Shirley viscometer has a stationary flat plate (lower section) and a conical disc (upper section). In practice, a small sample (<1 cc) is placed on the flat plate, which is then raised until the apex of the conical section just touches the plate. The emulsion is held in the gap by its own surface tension. The cone is then rotated by a variable-speed motor through a gear train and torque spring. The torsion due to the consistency of the fluid is measured by a potentiometer on a spring, which sends a signal to an X-Y recorder and a dial indicator. The motor is a dc motor-generator which feeds back a voltage directly in proportion to the rotational velocity of the cone. This voltage is fed into an amplifier unit and compared with a stable reference voltage. Thus, the system is a velocity servomechanism which produces a speed virtually independent of the slurry consistency on the cone. A tachometer is fitted to the dc motor-generator, and it feeds a signal to the recorder. Thus, a plot of rpm (shear rate) on the Y-axis and torque (shear stress) on the X-axis of the recorder is obtained.

The movable bottom plate is provided with an electrical connection that indicates on the control unit dial when the plate is just touching the apex of the cone. This setting is achieved reproducibly to within 0.0001 inch by means of a micrometer adjustment at the base. Once set and locked, the plate and cone can be separated for cleaning and addition of test samples and then returned to this position without subsequent adjustment. The plate is fitted with a cooling system and has three thermocouples embedded therein which are in direct contact with the test fluid in the gap. This permits accurate temperature measurements of the emulsion during the run.

The instrument is provided with three cones each having a different cone angle for use with gels and emulsion. By means of cone angle ($<1^\circ$), rpm range (0-1000), and spring torque (2.4 dynes/cm

of torque per scale division or 1200 dynes/cm for full-scale deflection), shear rates from 0 to 20,000 sec^{-1} and shear stresses from 0 to 562, 500 dynes/cm^2 can be obtained.

2. Capillary Viscometer - The capillary viscometer used for determining the shear stress-shear rate relationship consisted of a heavy-walled, stainless steel cylinder of 500 ml capacity. This cylinder was fitted with a capillary adapter plug, a nitrogen pressurization port, and a large cap to facilitate ready access for sample loading and cleaning. By using capillaries of different sizes, shear rates of 10^6 sec^{-1} could be obtained.

   In practice, the cylinder body was filled with the sample to be tested. Nitrogen was admitted at a given pressure, and a sample of the exudate was collected over a specified period of time and its mass was determined. The shear rate (SR) was calculated from the equation

$$SR = 32Q/\pi D^3$$

where Q = flow rate of the material, cm^3/sec

D = diameter of the capillary, cm

The shear stress (SS) was calculated as follows:

$$SS = \frac{\Delta P}{L} \times \frac{D}{4}$$

where ΔP = pressure drop across the capillary in dynes/cm^2

D = diameter of the capillary, cm

L = capillary length, cm

Shear stree-shear rate relationships at various temperatures were obtained by operating the viscometer in a controlled temperature cabinet.

Pressure Drop and Nozzle Spray Studies

The facility used to evaluate the pressure drop and nozzle spray patterns of the emulsified JP-4 consisted of two piston tanks with a common hydraulic reservoir (isopropyl alcohol). The isopropyl alcohol was flowed into the piston, thereby displacing the JP-4. JP-4 flow rate was determined by measuring the flow of alcohol into the piston. This facility is pictured in Figure 2.

To determine the pressure-drop characteristics of the emulsified JP-4, tubing similar to that existing in the CH-47 helicopter fuel system was used. One of the piston tank assemblies was used with the manifold, which was a straight section of 1-inch OD by 268-inch long aluminum tubing, with a 0.049 inch wall thickness. Pressure drop was measured with a Teledyne pressure transducer and a Brown recorder.

For the nozzle atomization tests, a 10-micron paper aircraft filter was used to prevent clogging of the nozzles. With the simplex orifice nozzle, only one of the piston tank assemblies was needed; however, both were needed for the dual orifice nozzle. This was required because different flow rates are needed across the primary and secondary portions of this nozzle.

RESULTS

RHEOLOGY

Yield Point

Yield Point as a Function of Temperature

The yield point (Rising Sphere method) of the unaltered emulsified JP-4 versus temperature (130° F, 77° F, 40° F, 10° F, and -20° F) was measured. As shown in Figure 3 and Table I, the yield point decreases rapidly when the temperature is increased, particularly in the temperature range of from -20° F to 80° F. Above 80° F, the change in yield point versus temperature is very much less pronounced, and it seems to approach a limiting value at approximately 140° F.

Yield Point as a Function of Mixing Time and Aging

The yield point (Rising Sphere method) of the altered ("as is" material mixed for given times) emulsified JP-4 was determined as a function of mixing time and subsequent storage time. The results are shown in Table II. Examination of the data indicates that (1) the yield point of the emulsion can be increased by longer mixing times, (2) the yield point tends to revert to its original value during storage, and (3) the reversion takes place at a faster rate for the more highly altered emulsion, e.g., 10 minutes' mixing time.

Yield Point as a Function of Measurement Method

The yield point of unaltered emulsified JP-4 (approximately 16 weeks' storage) was measured using the Rising Sphere method and the Cone Penetrometer method. The values obtained in very close agreement, i.e., 775 dynes/cm^2 (Rising Sphere method) and 788 dynes/cm^2 (Cone Penetrometer method).

Relation of Shear Stress to Shear Rate for JP-4 Emulsion

Shear Stress-Shear Rate Relationship Versus Temperature

The relationship between the shear stress and shear rate of the unaltered emulsified JP-4 fuel has been determined by using the

capillary rheometer in the range of 0 to 10^5 sec^{-1} at -20° F, 77° F, and 130° F. As shown in Figures 4, 5, and 6 and Table III, the shear stress-shear rate relationship (or apparent viscosity at a given shear rate) of the unaltered emulsified JP-4 fuel shows little dependence upon temperature. In fact, at 10^5 sec^{-1} shear rate, the apparent viscosity is essentially independent of temperature over the range of -20° F to 130° F. It is to be noted that the shear stress-shear rate plots show a break toward the shear stress axis at -20° F and toward the shear rate axis at both 77° F and 130° F. An investigation of this anomalous behavior of the emulsified fuel at low and elevated temperatures is beyond the contract scope. However, the changes in slope occur at about the same shear rate (10^4 sec^{-1}) regardless of temperature. This fact suggests that the shear rate, rather than the temperature, governs the shear stress-shear rate relationship of emulsified JP-4 fuel.

Shear Stress-Shear Rate Relationship Versus Mixing Time

The shear stress-shear rate relationship, i.e., apparent viscosity at a given shear rate, of altered emulsified JP-4 fuel was determined over the shear rate range of 0 to 2 x 10^4 sec^{-1} at 77° F by using the cone and plate viscometer. The results are given in Table IV. The data show that (1) the apparent viscosity at shear rates of 10^2 and 10^3 sec^{-1} increases slightly as the mixing time (altering method) increases, and (2) the apparent viscosity at shear rates of 10^4 and 2 x 10^4 sec^{-1} appears to be independent of mixing time.

INTERNAL PHASE DROPLET SIZE DETERMINATION

Aging Studies

Photomicrographs were taken of the unaltered emulsified JP-4 at the initiation of the program and after 6 and 12 weeks' storage. The slides which were best in focus were selected, and every droplet on these slides was measured. This information was placed in the computer program, which calculated mean droplet diameter and standard deviation (Tables V, VI, and VII). The information from the computer outputs was used to plot the droplet size distribution graphs, shown in Figures 7, 8, and 9. Figures 10 through 13 show the photomicrographs from which the data were obtained.

Table VIII summarizes the mean droplet diameters of the stored and unstored emulsion. The only significant change in the results is a decrease

in the mean droplet diameter after 12 weeks' storage. This is not in accord with what one would expect. As the emulsion ages and the yield point decreases, one would presume that smaller droplets would coalesce to form larger ones, therefore increasing the mean droplet diameter. However, the results do not bear this hypothesis out.

Mixing Studies

Photomicrographs were taken of emulsified JP-4 after it was mixed (altered) for 3, 5, and 10 minutes. The slides in best focus were chosen for study (Figures 17, 18, and 19). Every droplet on these slides was measured, and this information was placed in the computer. The tabulated results, including the mean droplet size and the standard deviation, are shown in Tables IX, X, and XI. The data were used to plot a droplet size distribution curve for each slide (Figures 14, 15, and 16).

The data for mean droplet diameter and standard deviation as a function of mixing time are summarized in Table XII. This shows a significant decrease in the mean droplet diameter after 3 minutes' mixing, with no further alteration occurring as mixing time is extended. This gives little insight into the mechanism, which imparts a higher yield point as mixing time increases.

There was a difference in the clarity of the definition of the emulsion droplets observed under the microscope. This was especially true of the material, either altered or unaltered, which was investigated toward the end of the program (see Figures 13 and 18). In some cases, pockets of discrete spherical droplets were photographed, as shown in Figures 17 and 19, which are considered to be representative of the internal phase; however, the overall structure did not compare favorably with the emulsion droplet configurations illustrated in Figure 12, where many of the droplets have hexagonal shapes. Also, in many cases, positions of the emulsion smear showed a large area of continuous phase. It is possible that these pockets of continuous phase are evidence of a partial inversion from an oil in water emulsion to a water in oil emulsion. The emulsion also appears to undergo a slow degradation in yield value with time. When the emulsion was first received, its yield point was around 1100 dynes/cm^2. Toward the end of the program, approximately three months later, the yield point of the as received material was approximately 750 dynes/cm^2.

PRESSURE DROP STUDIES

Pressure drop characteristics of the emulsion passing through a 1-inch OD by 268-inch-long aluminum tubing were obtained for three samples of emulsion. Each sample was given a different yield point by varying the mixing time. This yield point was measured immediately preceding the flow, as the value decreases quite rapidly after mixing.

Each sample was flowed at several flow rates over the normal operating range of the CH-47 helicopter. The results of these tests are shown in Figure 20. Examinations of these data indicate that yield point has little effect on the pressure drop characteristics of the emulsion in the test manifold.

NOZZLE STUDIES

The fuel was flowed through two types of gas turbine atomizing nozzles: a simplex orifice and a dual orifice (these nozzles are used in the T-55 engine). The spray pattern of the simplex orifice was investigated at its normal operating flow rate for the start cycle (12 lb/hr, with 105 psid); the pattern of the dual orifice was investigated at the flight idle condition (primary flow rate - 11.1 lb/hr, secondary flow rate - 3.5 lb/hr, with 10-20 psid across both sections of nozzle). Each nozzle was tested with neat JP-4 and two emulsified JP-4 samples with yield points of 800 and 2400 dynes/cm^2.

During these tests, as was previously noted, a 10-micron paper filter was used to prevent clogging of the nozzles. The emulsion was flowed through the system (at the proper flow rates) without the nozzles, to determine the degree of emulsion breakdown through the filter. Breakdown was determined by measuring the amount of material that passed through a 200-mesh screen; the material that passed through was assumed to be broken-down emulsion. Subsequently, the nozzles were placed in the system, and the material exiting from the nozzles was also collected. This was done to ascertain the degree of further breakdown achieved through the nozzle. Thus, the extent of emulsion breakdown at the inlet and outlet of the nozzle was ascertained. The data are presented in Table XIII.

It was noted during these flow tests that the material collected was not of uniform consistency; that is, at various times during flow, the emulsion was either completely broken down or intact. Therefore, the values shown in Table XIII represent a time-averaged consistency. In the case of the 800 dynes/cm^2 yield point material, considerable breakdown

occurred in the filter and significant additional breakdown occurred through the nozzle; however, the higher yield point material (2400 dynes/cm^2) did not break as much as the 800 dynes/cm^2 material and did not show significant additional breakdown in the nozzle.

Simplex Orifice Nozzle

The photographs taken of the JP-4 passing through the simplex nozzle were treated in two ways.

First, a qualitative analysis of all the spray patterns was undertaken. This included measurement of the spray angle and a measurement of the fuel sheet length from the nozzle to the point of breakup. The data are presented in Table XIV. There was a random variation of the spray angle, ranging from 87° to 102°; however, no difference was noted for either the neat JP-4 or the emulsified JP-4. Generally, the emulsified JP-4 had a shorter fuel sheet length than the neat liquid, but there was more variation with the emulsion, especially when the higher yield point material was used. It was also observed that, during flow, the higher yield point emulsion gave an audible variation and a change in color (from transparent to milky).

Second, a quantitative measure of the spray droplet size distribution was undertaken. One picture was chosen for both the neat liquid and the emulsified JP-4 with an 800 dynes/cm^2 yield point; two pictures were used for the higher yield point emulsion to determine if a variation in droplet distribution could be seen. In each picture, the area in best focus was selected and defined by boundary lines; every drop within this area that was in the focal plane of the camera was measured. Figures 25 through 28 show the pictures which were used for these measurements.

The data collected were placed in the computer program, which computed the mean droplet diameter and the standard deviation for each picture. From this computer output (Tables XV to XVIII), a droplet size distribution curve was constructed for each picture, shown in Figures 21 through 24.

A summary of the mean droplet diameter and standard deviation for each picture is presented in Table XIX. There is no significant difference between the neat liquid and the emulsified JP-4 with an 800 dynes/cm^2 yield point, but both pictures of the higher yield point emulsion show a mean droplet diameter twice the size of that obtained with these two materials. This would indicate that when the nozzle does not completely break up the emulsion, a higher droplet diameter is obtained in the

spray. This could prove to be a drawback for emulsified fuels, since the larger droplets should take a longer time to burn, thus potentially causing damage to the engine by impinging on the turbine.

Dual Orifice Nozzle

The dual orifice nozzle did not atomize either of the emulsions with which it was tested. The spray pattern varied anywhere from a fully developed cone, as had been obtained with the neat liquid, to an unatomized sheet. This variation occurred at the same flow rate, during the same flow test, and represented a variation with time at that flow rate. Any attempt to obtain a droplet size distribution for these flow tests would be futile, since this distribution is constantly varying with time. Furthermore, such information would be quite useless, since the use of this nozzle for emulsion at these flow rates is obviously impractical. In a subsequent test the 800 dynes/cm^2 emulsion was run through the dual orifice nozzle at injector pressure drops approximately ten times that for flight idle conditions (primary - 135 psi, secondary 100 psi). Under this condition a fully developed cone was achieved. However, the amount of unbroken emulsion in the spray was significant ($\approx$50 percent). Further investigation will be required to determine what the droplet size was at this condition and to define the point at which a fully developed cone is first obtained.

Representative pictures for each of these flow tests are presented in Figures 30 through 36. Three pictures are shown for each of the emulsions tested (800 and 2400 dynes/cm^2); these pictures were taken at different times during the same flow tests. A drop size distribution was computed for the neat liquid; these data are shown in Table XXI and Figure 29. The mean droplet obtained was twice the size of that observed for neat liquid flowing through the simplex orifice nozzle and larger than emulsion droplets from the simplex nozzle.

In summary, the dual orifice nozzle is impractical for either of the emulsions tested, and the simplex orifice nozzle yields possibly an unacceptable atomization with the higher yield point emulsion. A possible mode of avoiding this problem is to de-emulsify the fuel before it reaches the nozzle. During this program, it was observed that small amounts of isopropyl alcohol would rapidly de-emulsify large quantities of emulsion.

CONCLUSIONS

The emulsified JP-4 exhibits pseudoplastic flow characteristics; that is, it shears thin under an applied stress and recovers almost instantaneously when the stress is removed. Flow data obtained on the emulsion show that its non-Newtonian viscosity changes very little over the temperature range of -20° to 130° F. The emulsion also has a yield point at 77° F which is 1150 dynes/cm^2. The yield point increases with decreasing temperature in an expotential manner from 7360 dynes/cm^2 at -20° F to 775 dynes/cm^2 at 130° F. The yield point appears to degrade slowly in value with aging.

It is possible to alter the rheology of the emulsified fuel by using a low shear mixer to mix it for a prescribed length of time. The alteration will result in an increased yield point of the system. After an interval of 2 to 3 days, it will relax.

The altered emulsion has a slightly smaller mean droplet size (0.8μ) than the unaltered material (1.4μ), but it does not decrease further if the mixing time is increased from 3 to 10 minutes. There is some evidence that the emulsion undergoes a partial inversion from an oil in water emulsion to a water in oil emulsion.

If the emulsion is flowed through a 1-inch line, the pressure drop at a given flow rate is not affected by a change in emulsion rheology. The spray pattern developed by the emulsion through a helicopter engine nozzle appears to be erratic, and it appears that the emulsion should be broken before it enters the nozzle.

RECOMMENDATIONS

It is recommended that:

In future programs, measurements of the internal phase droplet size and shape be made by using an electron microscope.

Additional studies be conducted to determine the cause of the temporary increase in yield stress due to mixing. One approach is to study closely the effect of small changes in emulsifier concentration on this characteristic.

The fuel be de-emulsified prior to entering the atomizing nozzle. This could be achieved either by mechanically shearing the emulsion or by injecting ammonia or alcohol to destroy the emulsion structure.

Additional storage studies be conducted to evaluate the effect of long-term storage on emulsion properties. These tests should be conducted under a variety of conditions over the anticipated storage temperature range and with a vibration schedule which would simulate that found in an operational application.

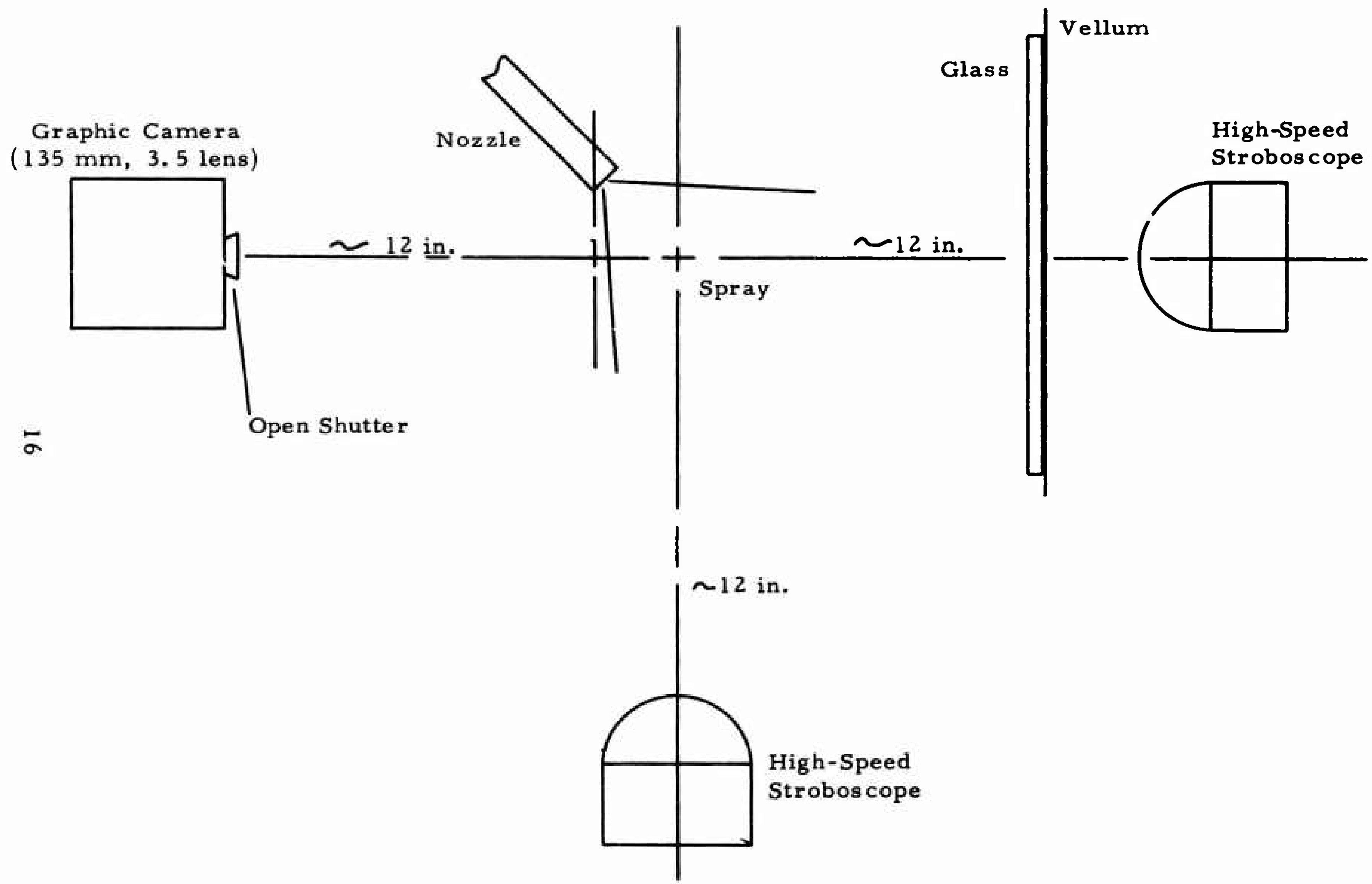

Figure 1. Photographic Apparatus for Nozzle Spray Droplet Size.

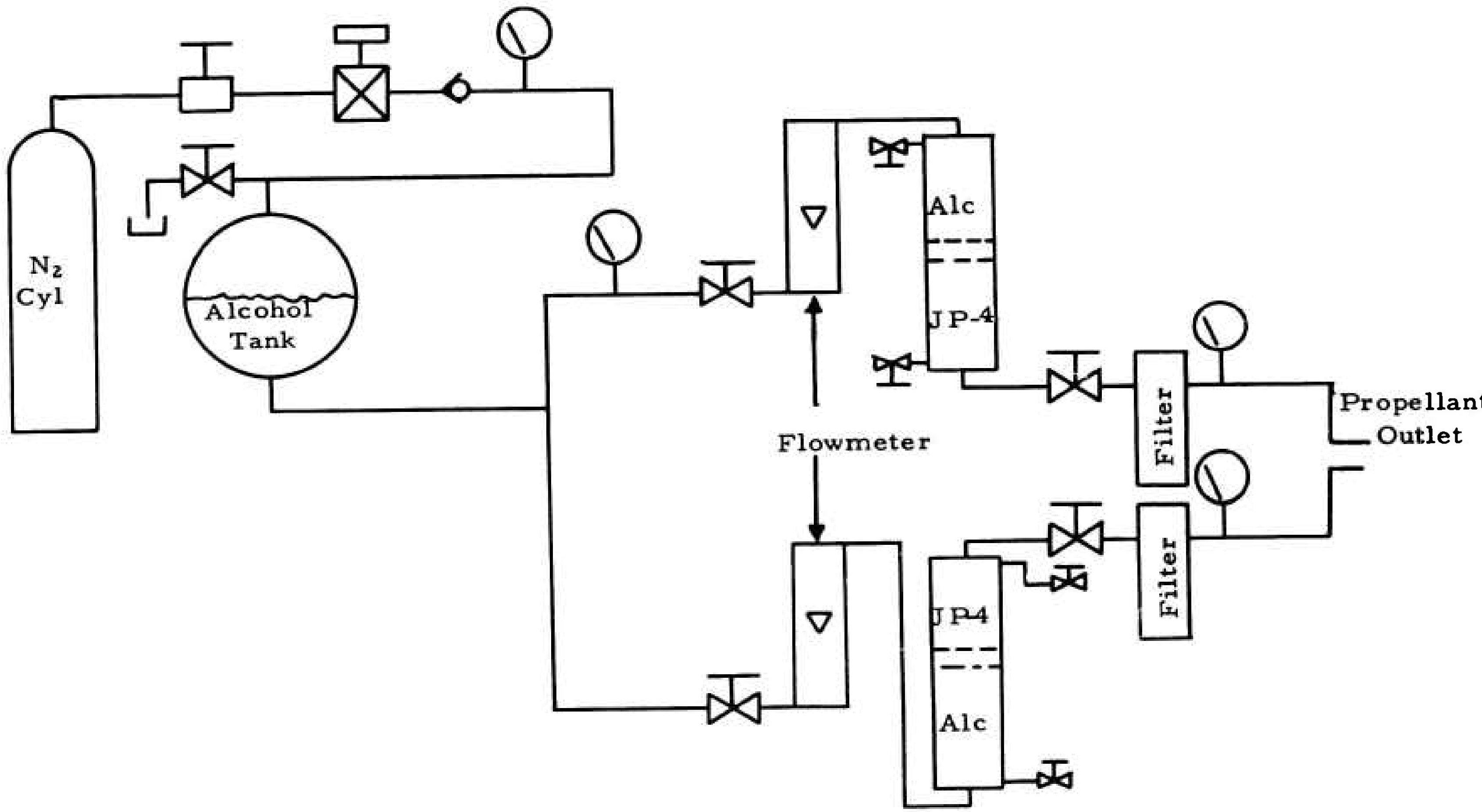

Figure 2. Propellant Flow Facility.

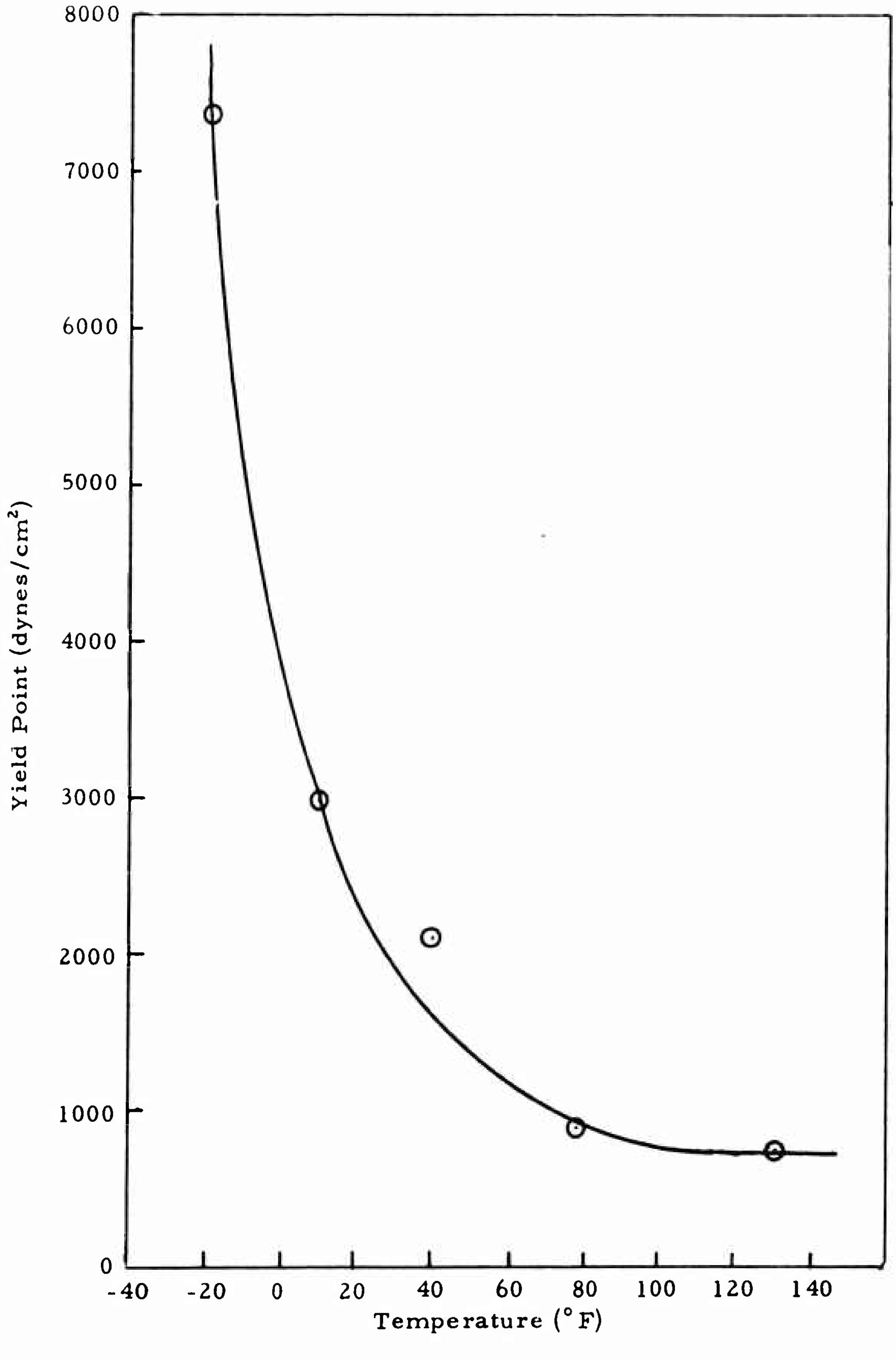

Figure 3. Emulsified JP-4 Fuel - Yield Point Vs Temperature.

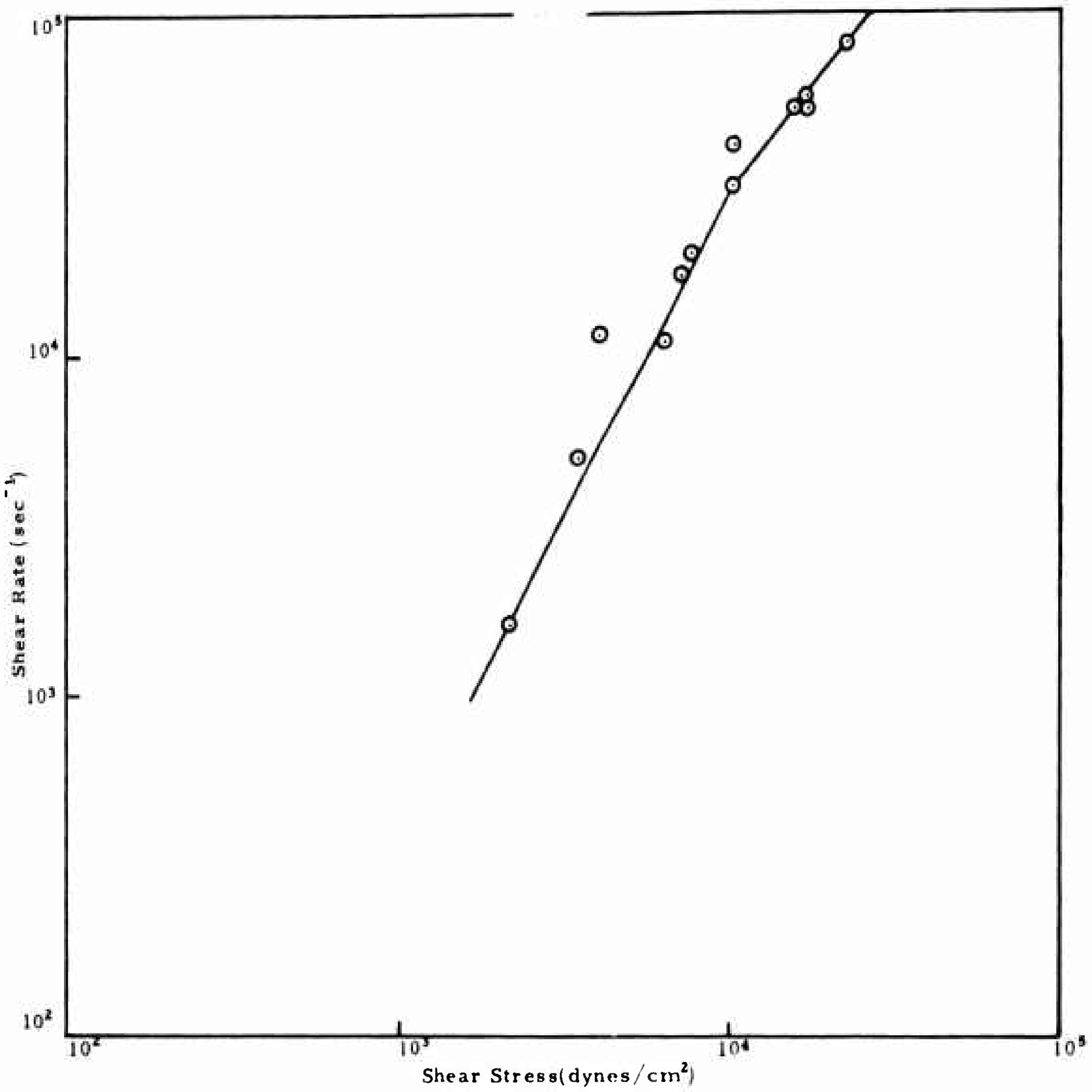

Figure 4. Emulsified JP-4 Fuel - Shear Stress-Shear Rate Relationship at -20° F.

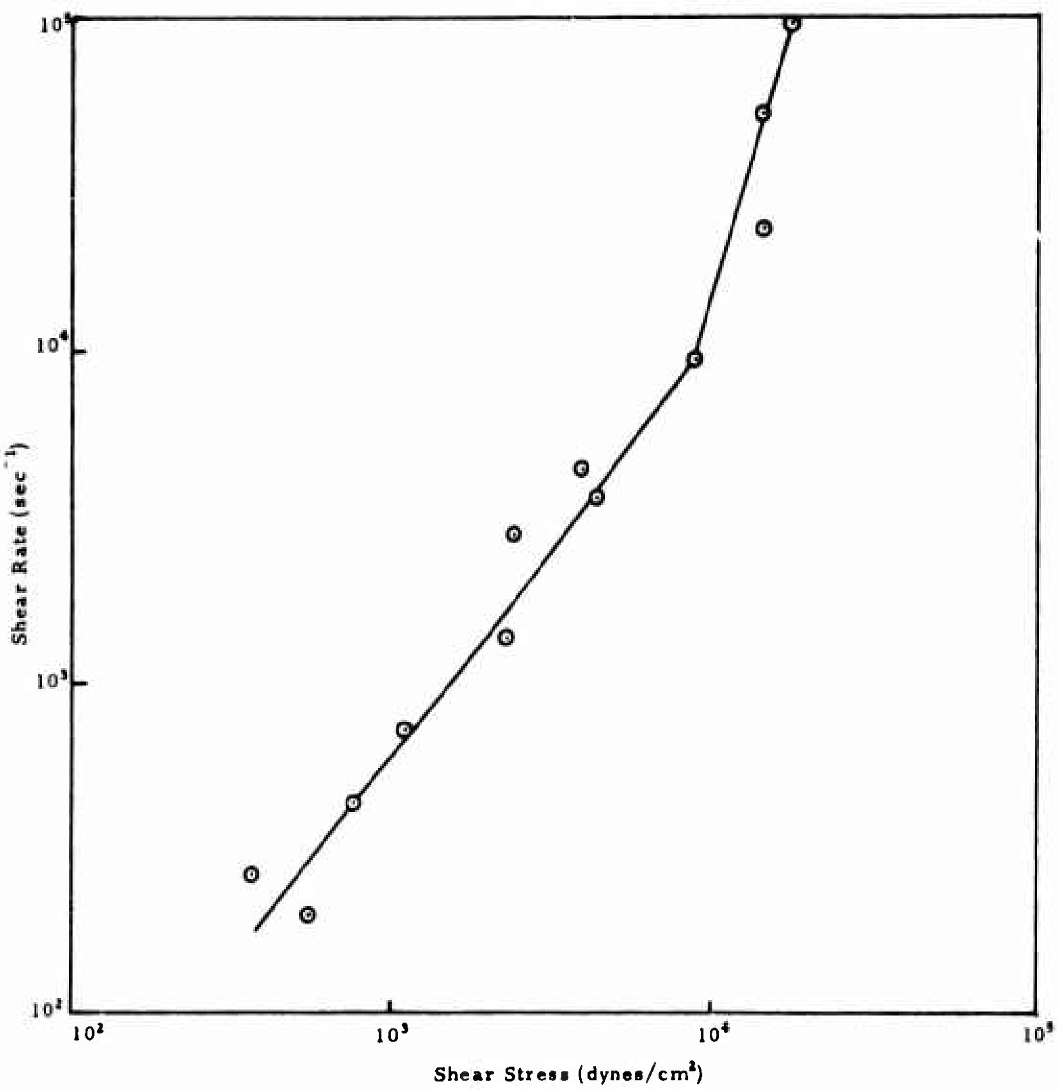

Figure 5. Emulsified JP-4 Fuel - Shear Stress - Shear Rate Relationship at +77° F

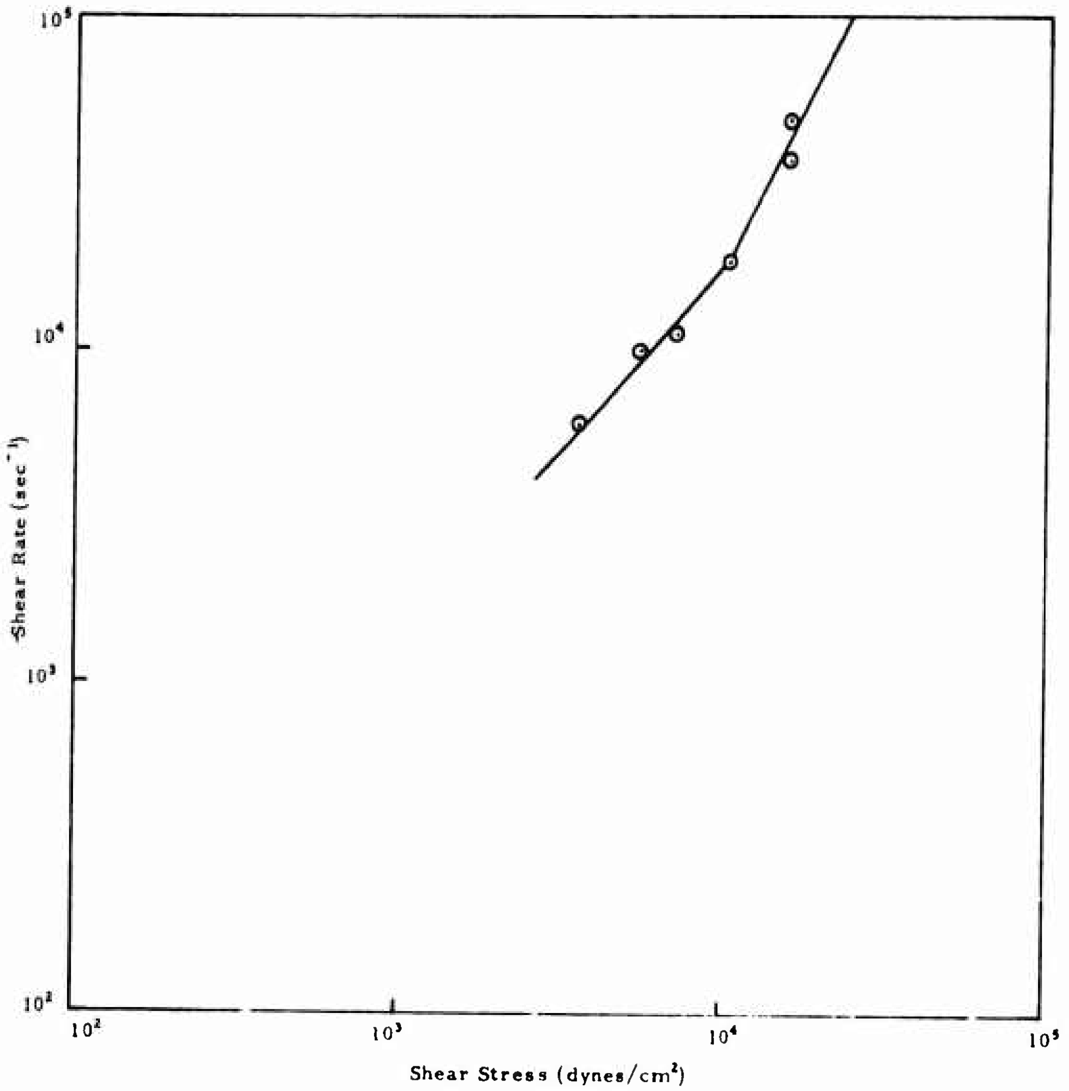

Figure 6. Emulsified JP-4 Fuel - Shear Stress-Shear Rate Relationship at +130° F.

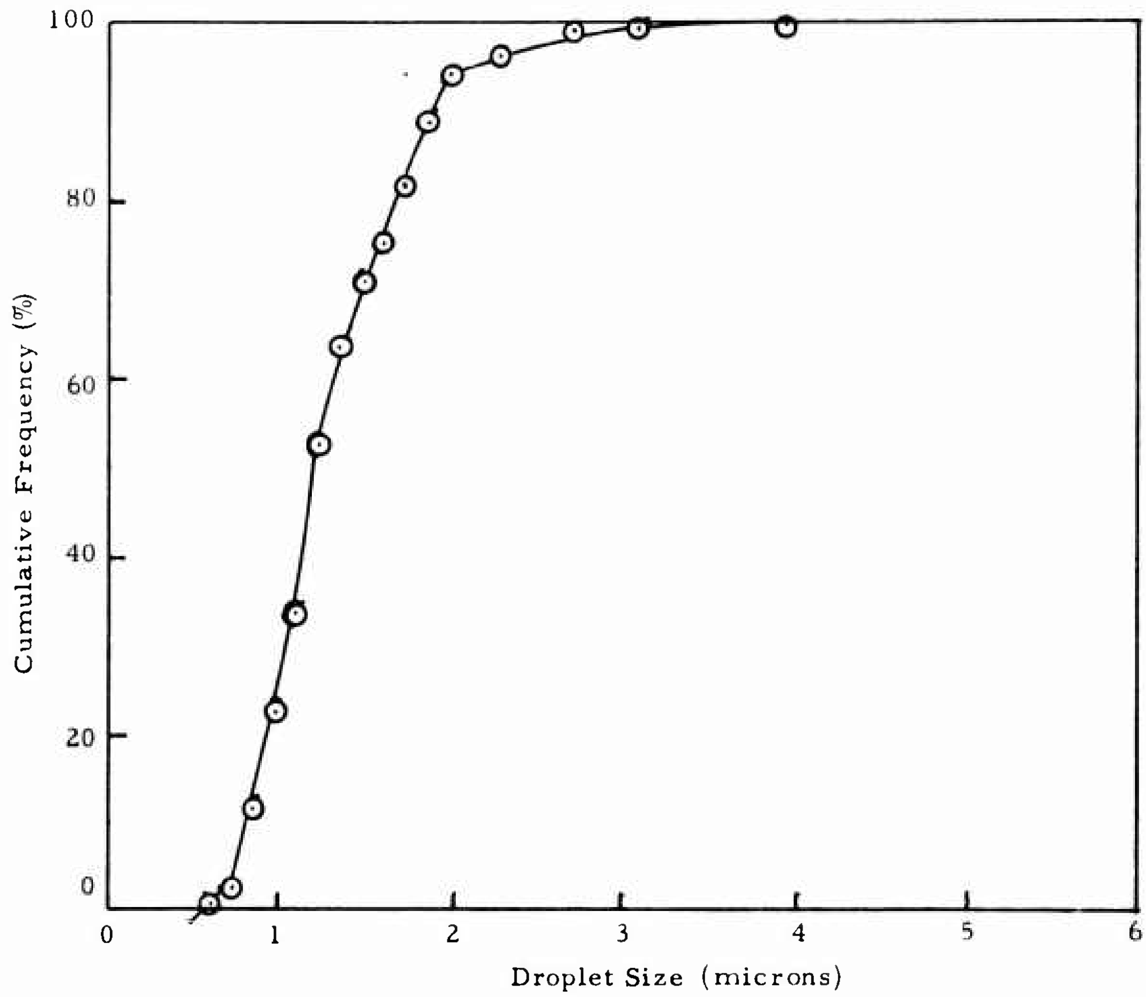

Figure 7. Emulsified JP-4 Fuel - Droplet Size Distribution of As Received Material.

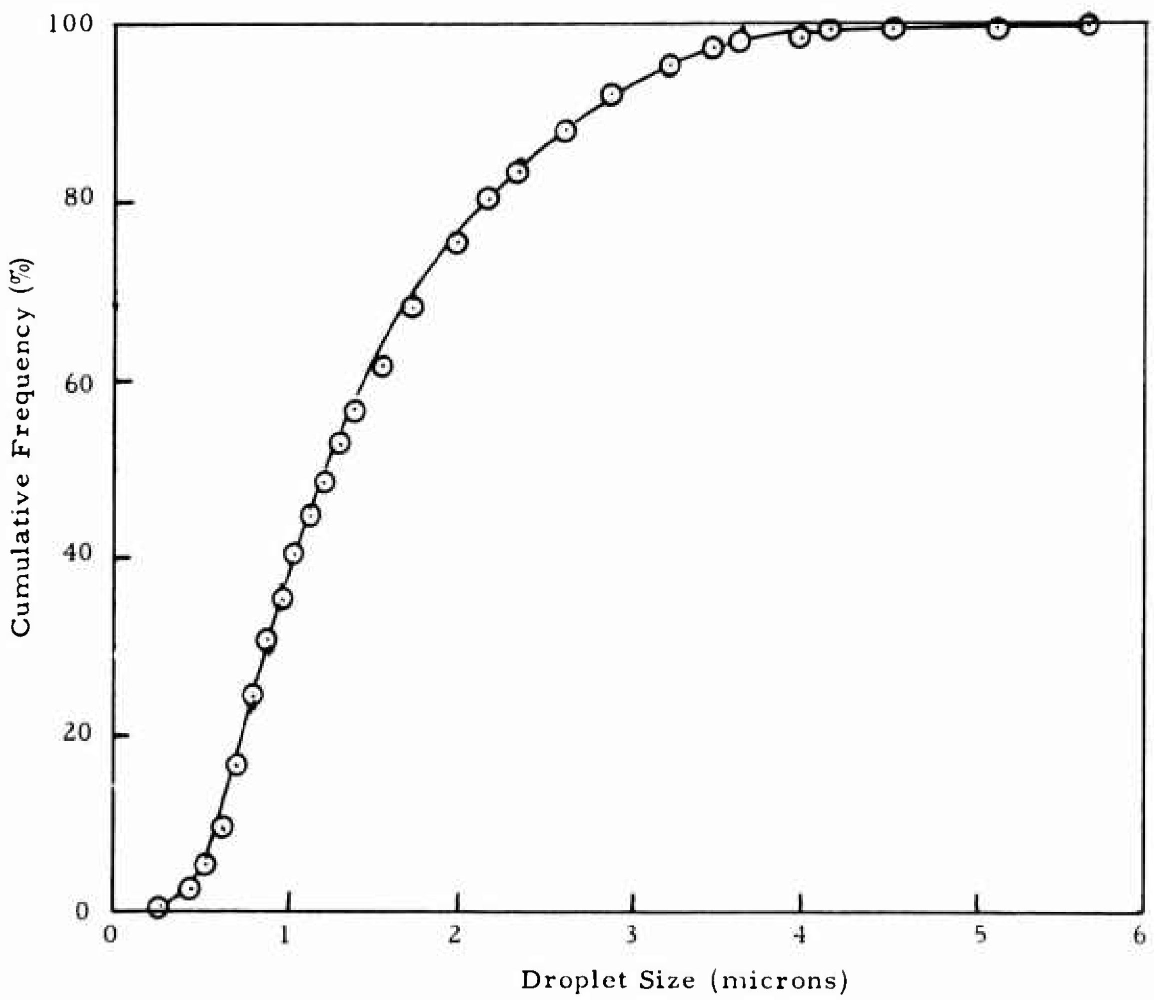

Figure 8. Emulsified JP-4 Fuel - Droplet Size Distribution After 6 Weeks.

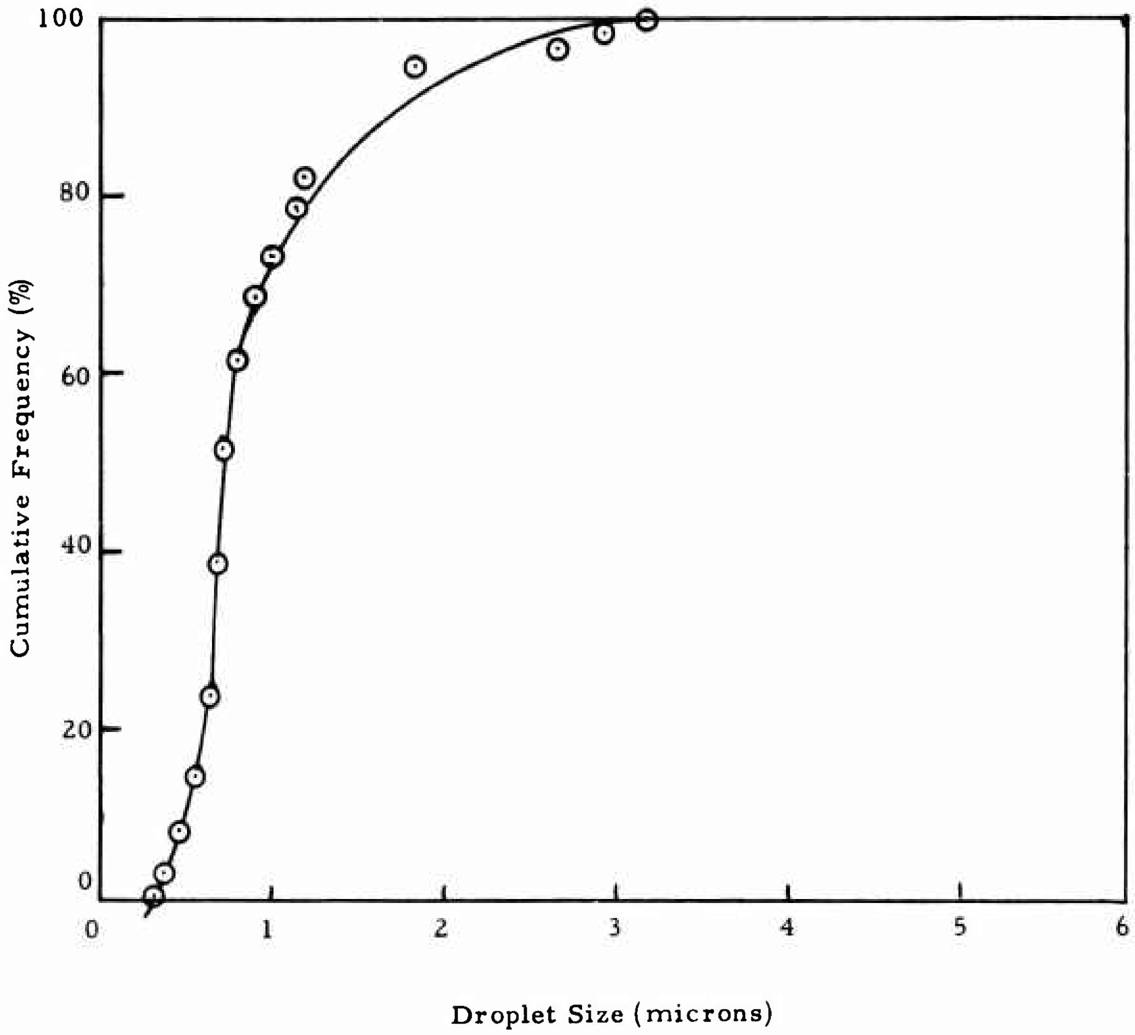

Figure 9. Emulsified JP-4 Fuel - Droplet Size Distribution After 12 Weeks.

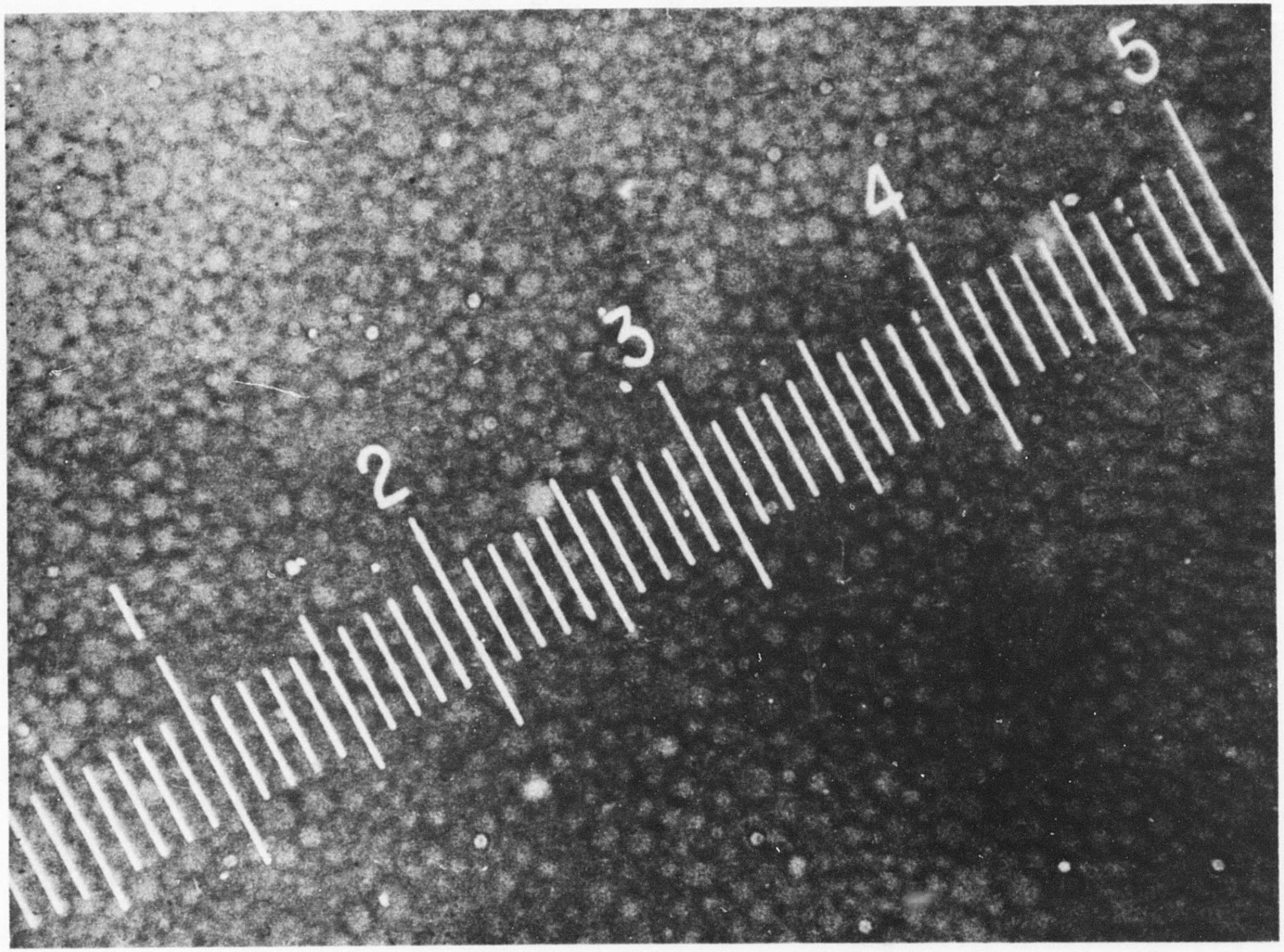

Figure 10. Photomicrograph of Internal Phase - Emulsified JP-4 Fuel - As Received.

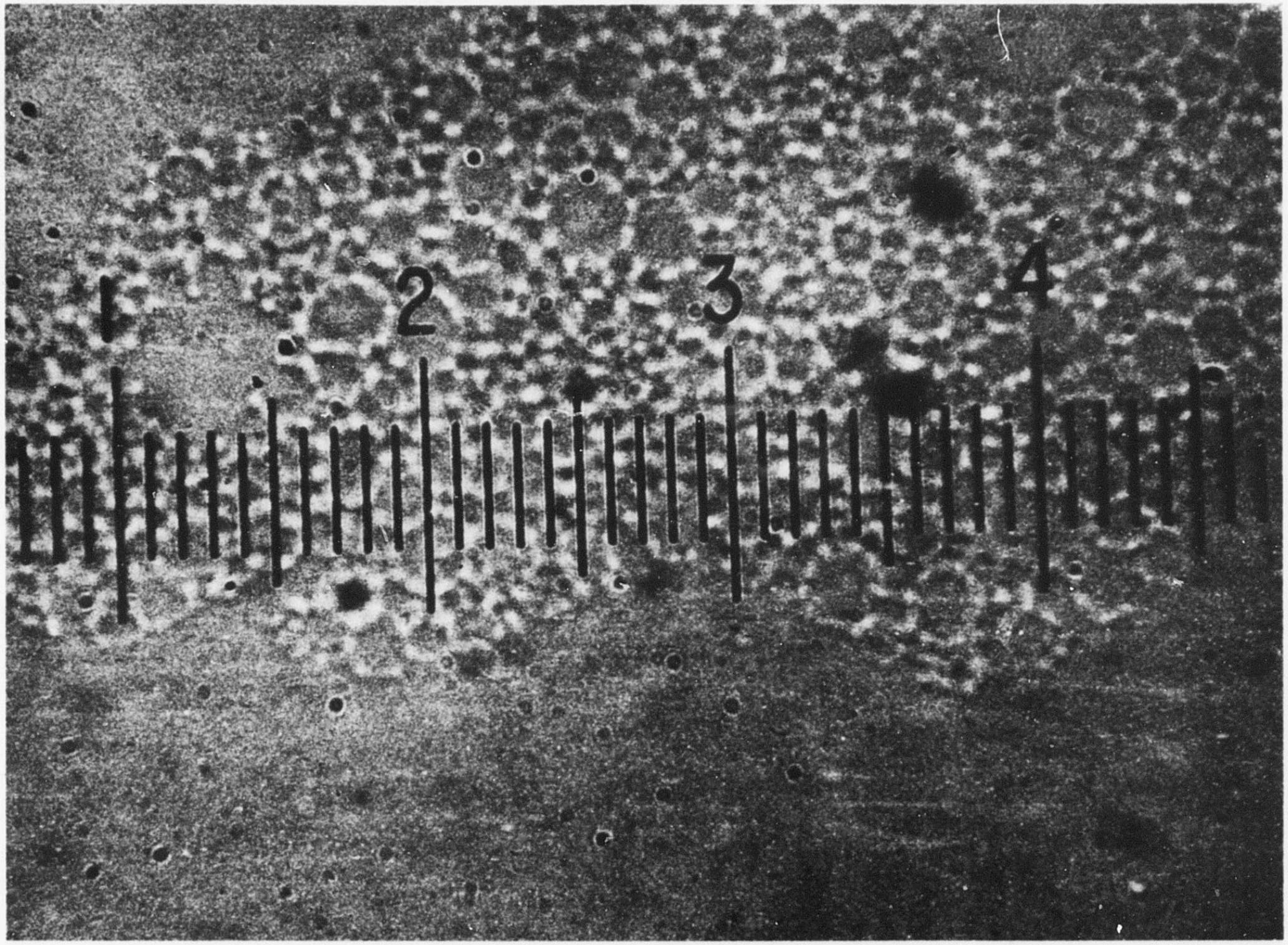

Figure 11. Photomicrograph of Internal Phase - Emulsified JP-4 Fuel - After 6 Weeks' Storage.

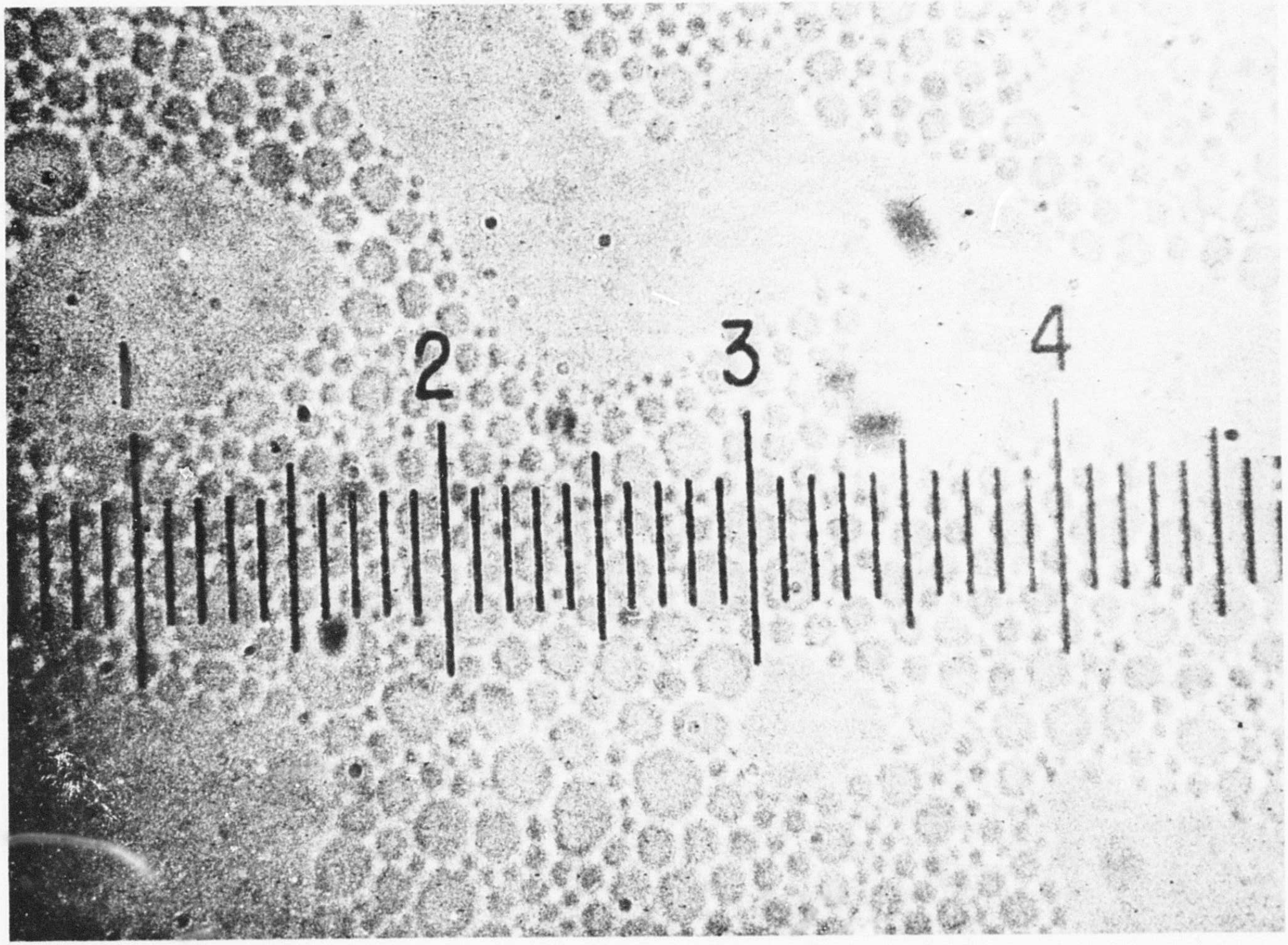

Figure 12. Photomicrograph of Internal Phase - Emulsified JP-4 Fuel - After 6 Weeks' Storage.

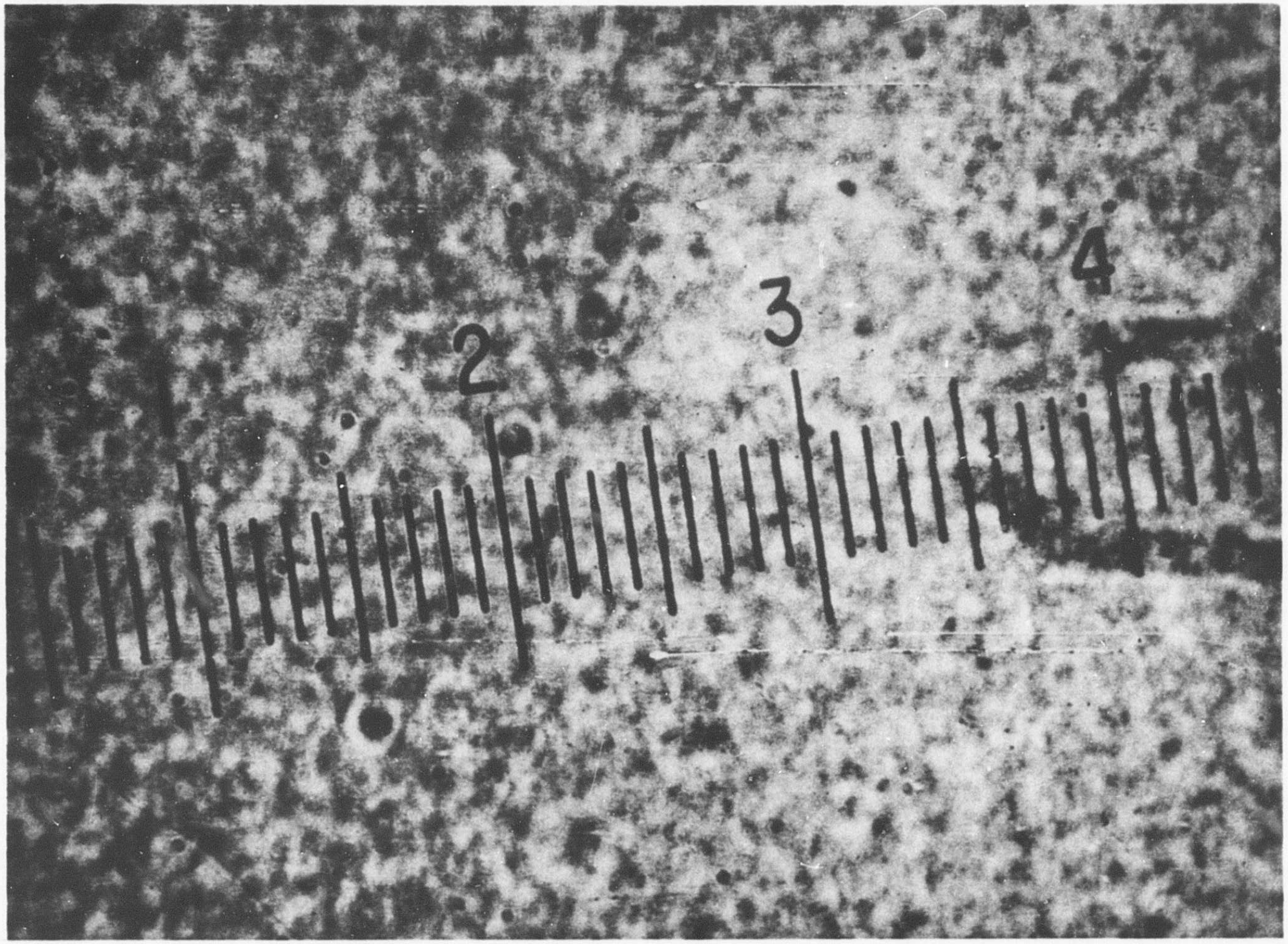

Figure 13. Photomicrograph of Internal Phase - Emulsified JP-4 Fuel - After 12 Weeks' Storage.

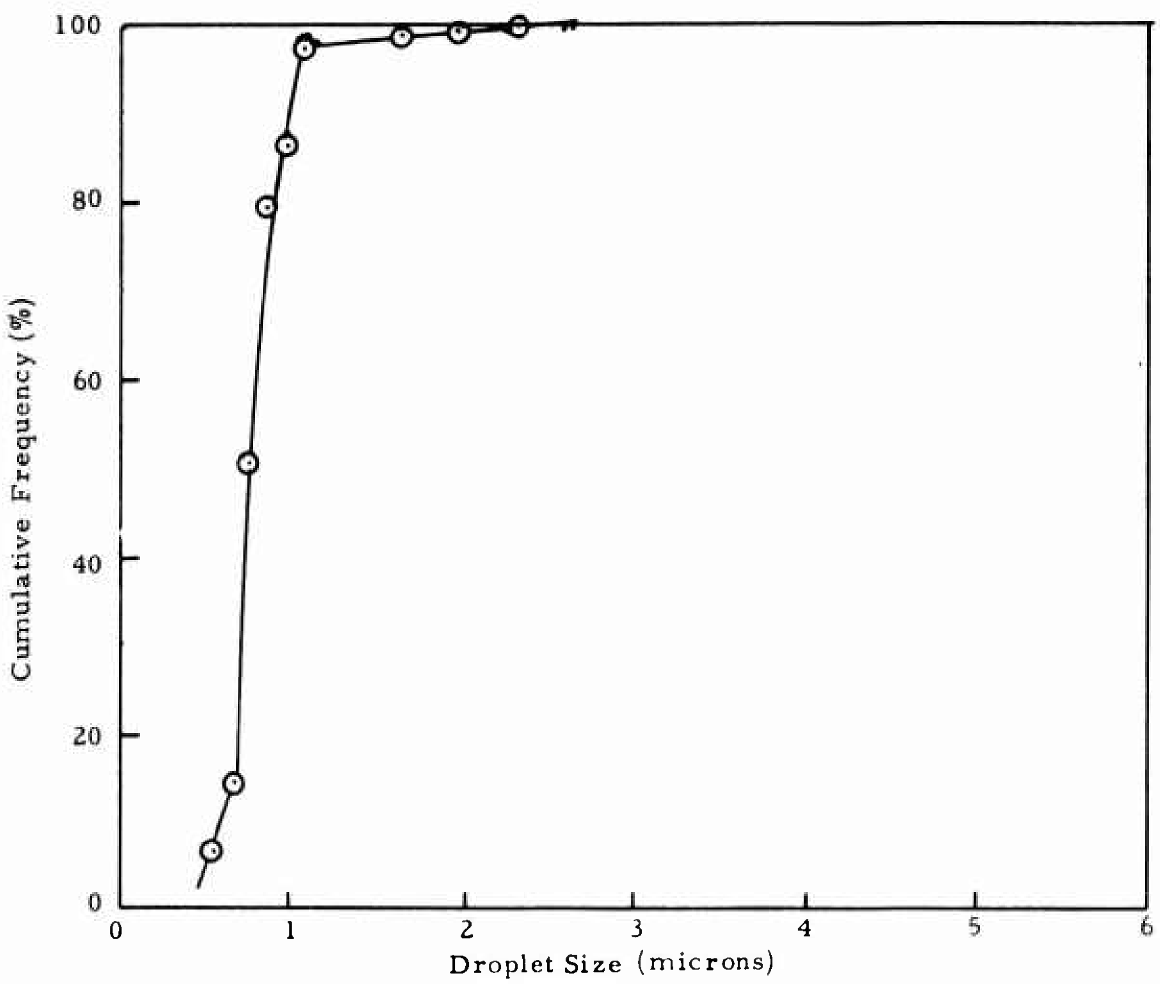

Figure 14. Droplet Size Distribution - Altered Emulsified JP-4 Fuel - 3 Minutes' Mixing Time.

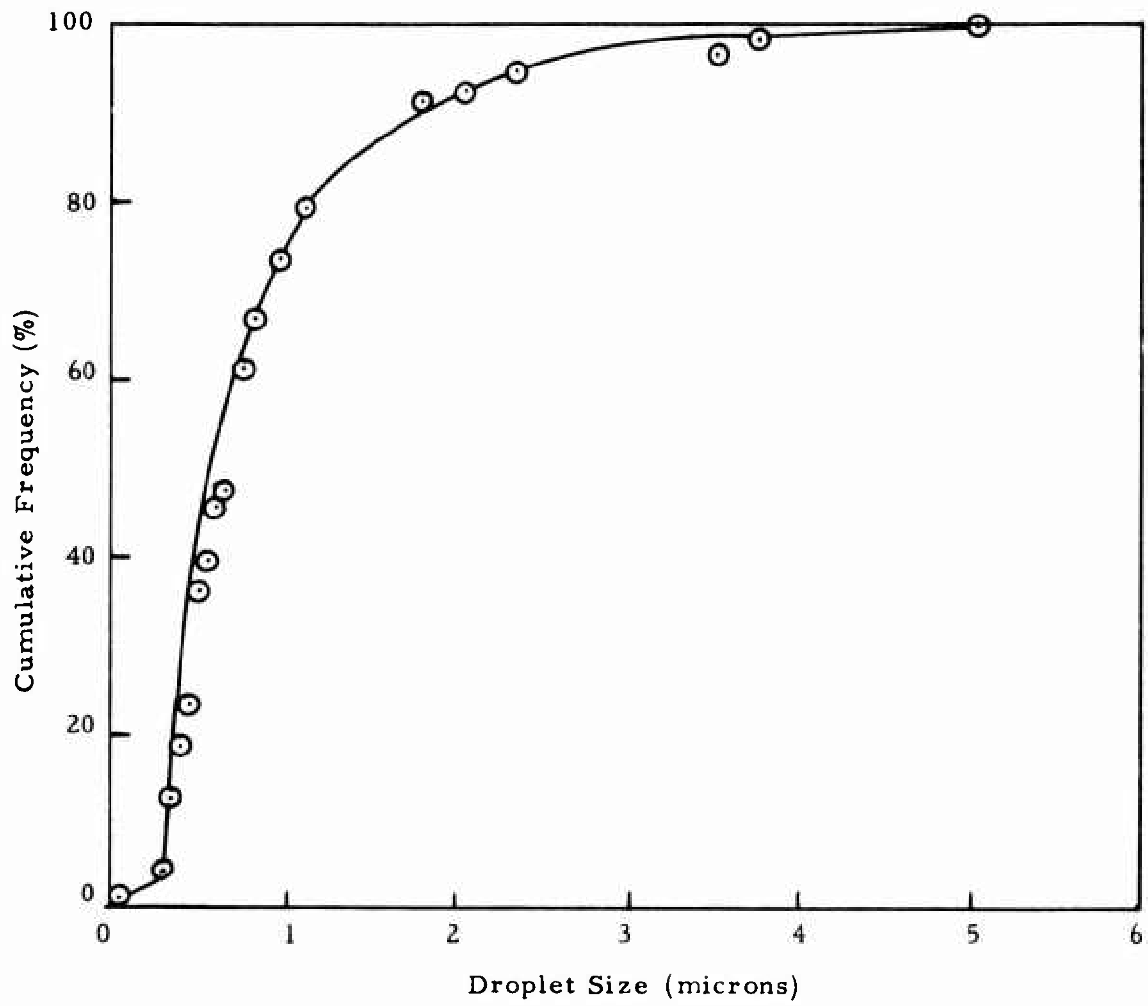

Figure 15. Droplet Size Distribution - Altered Emulsified JP-4 Fuel - 5 Minutes' Mixing Time.

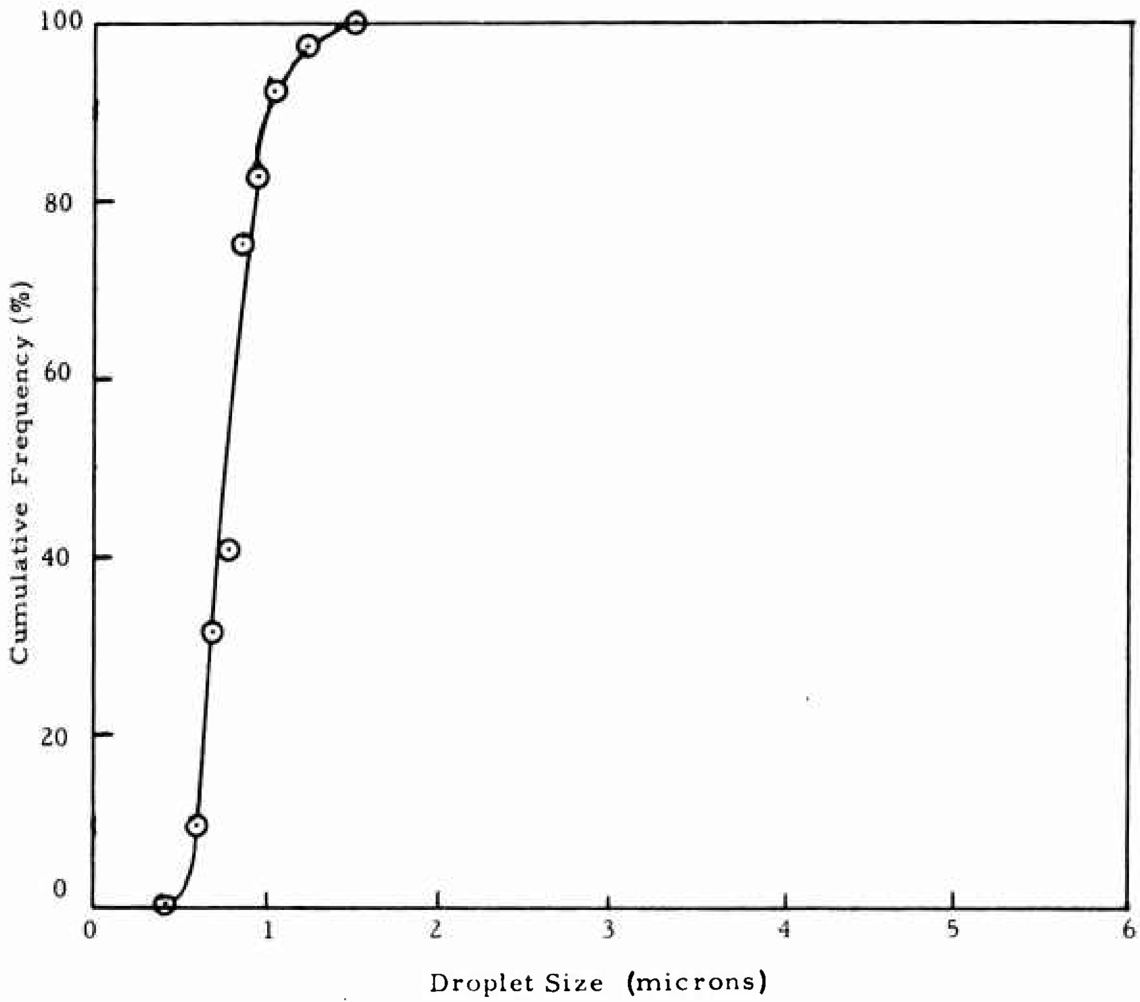

Figure 16. Droplet Size Distribution - Altered Emulsified JP-4 Fuel - 10 Minutes' Mixing Time.

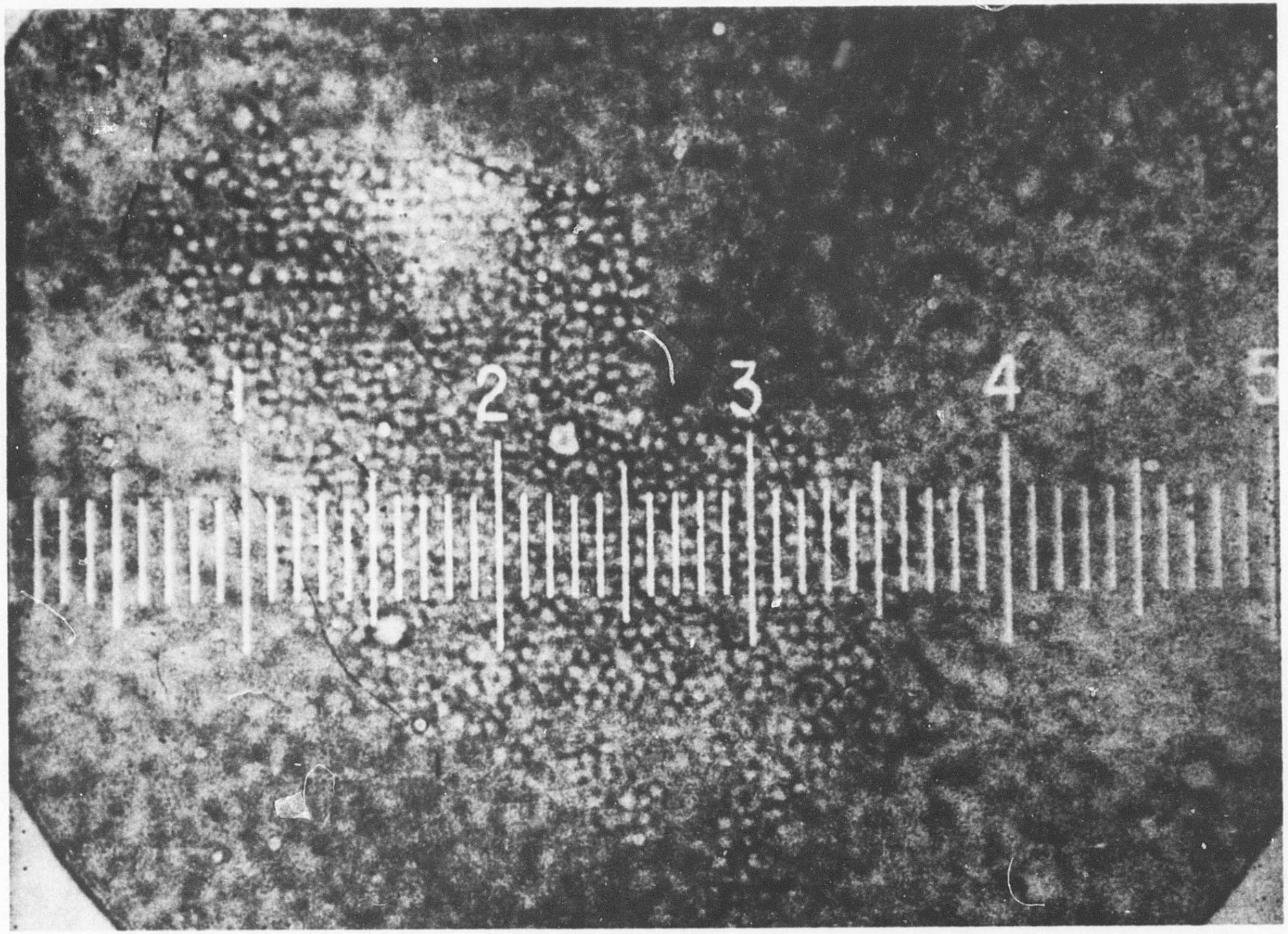

Figure 17. Photomicrograph of Altered Emulsified JP-4 Fuel - 3 Minutes' Mixing Time.

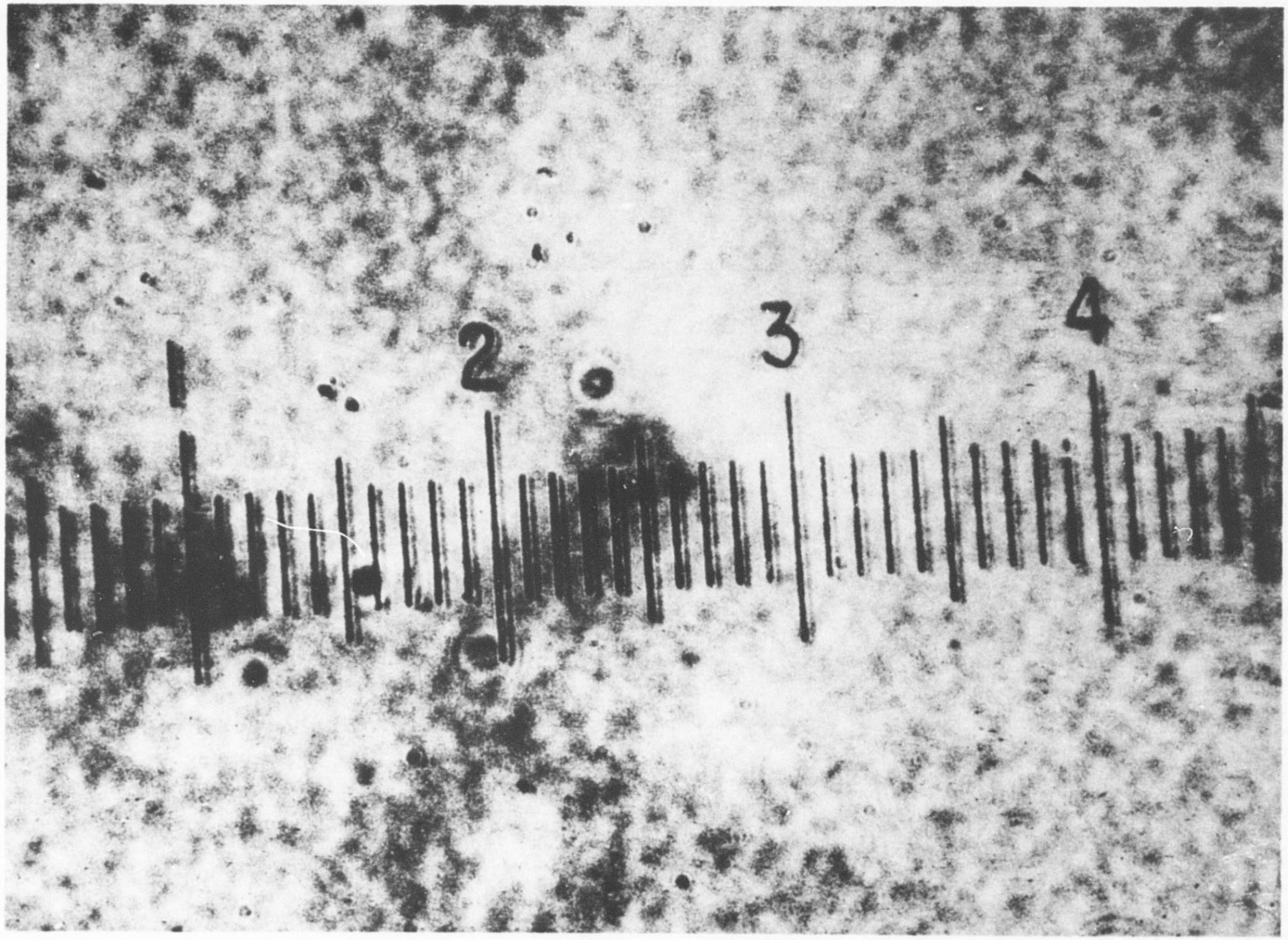

Figure 18. Photomicrograph of Altered Emulsified JP-4 Fuel - 5 Minutes' Mixing Time.

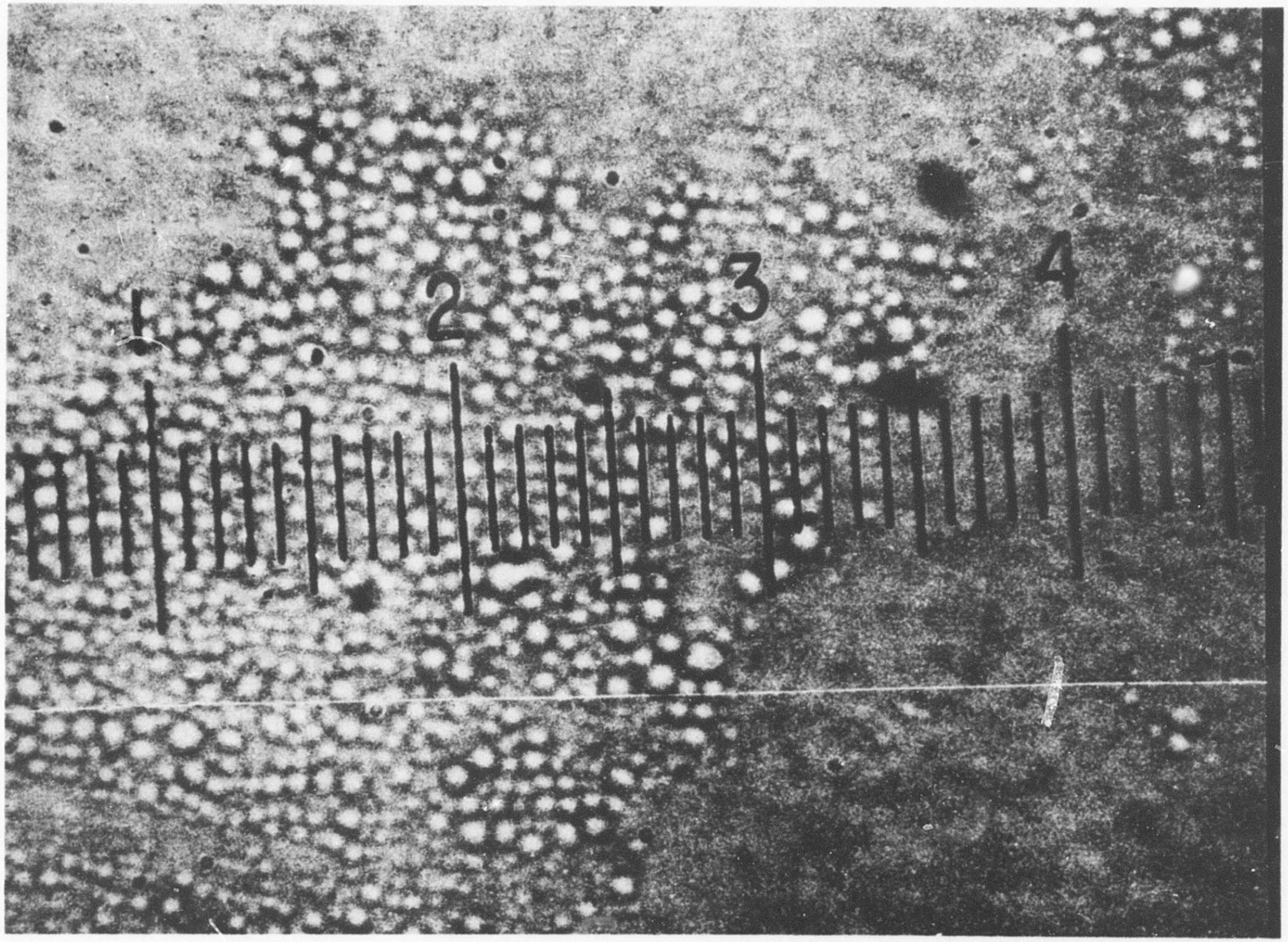

Figure 19. Photomicrograph of Altered Emulsified JP-4 Fuel - 10 Minutes' Mixing Time.

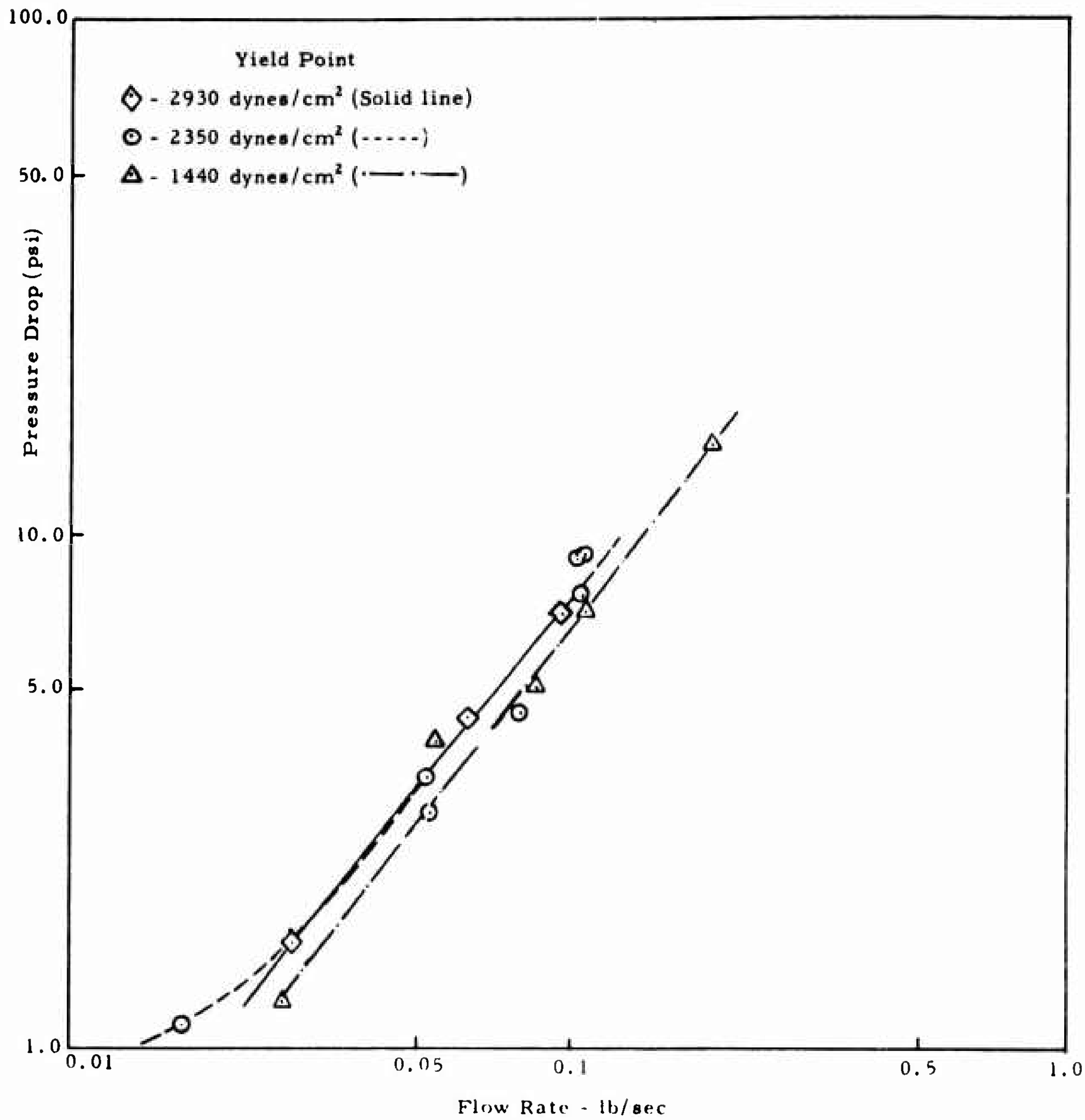

Figure 20. Pressure Drop Vs Flowrate.

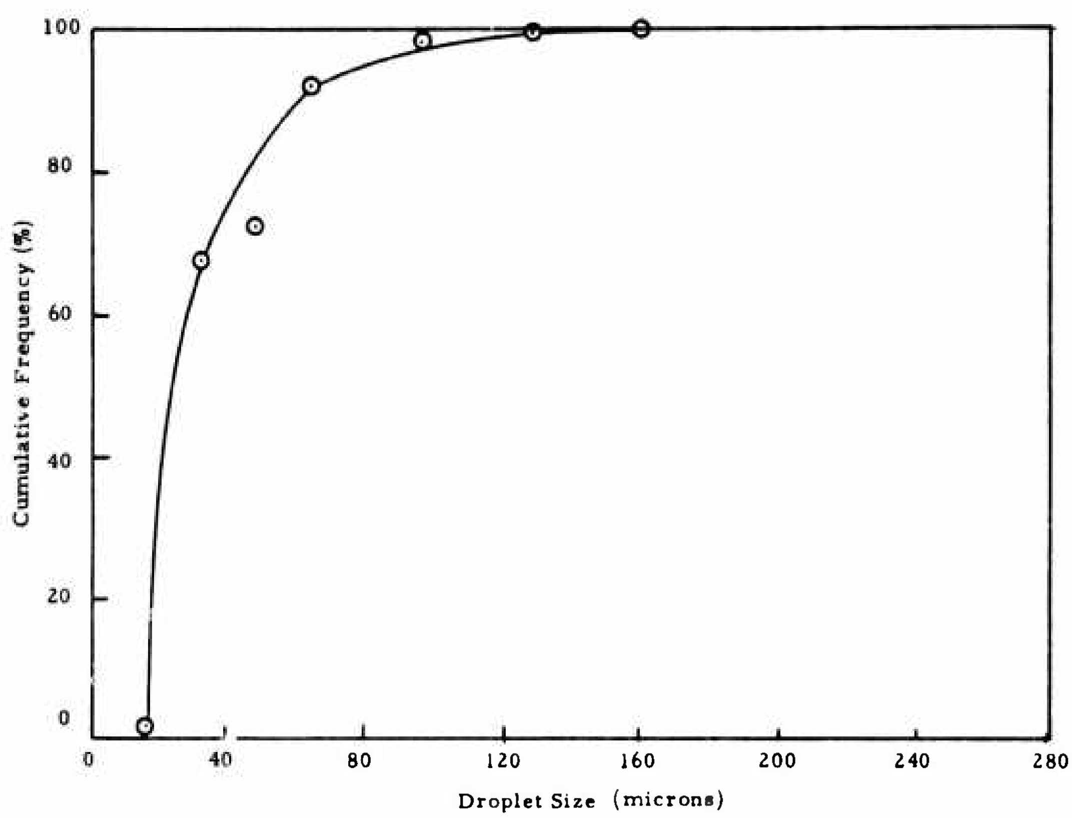

Figure 21. Droplet Size Distribution - Neat JP-4 - Simplex Orifice Nozzl

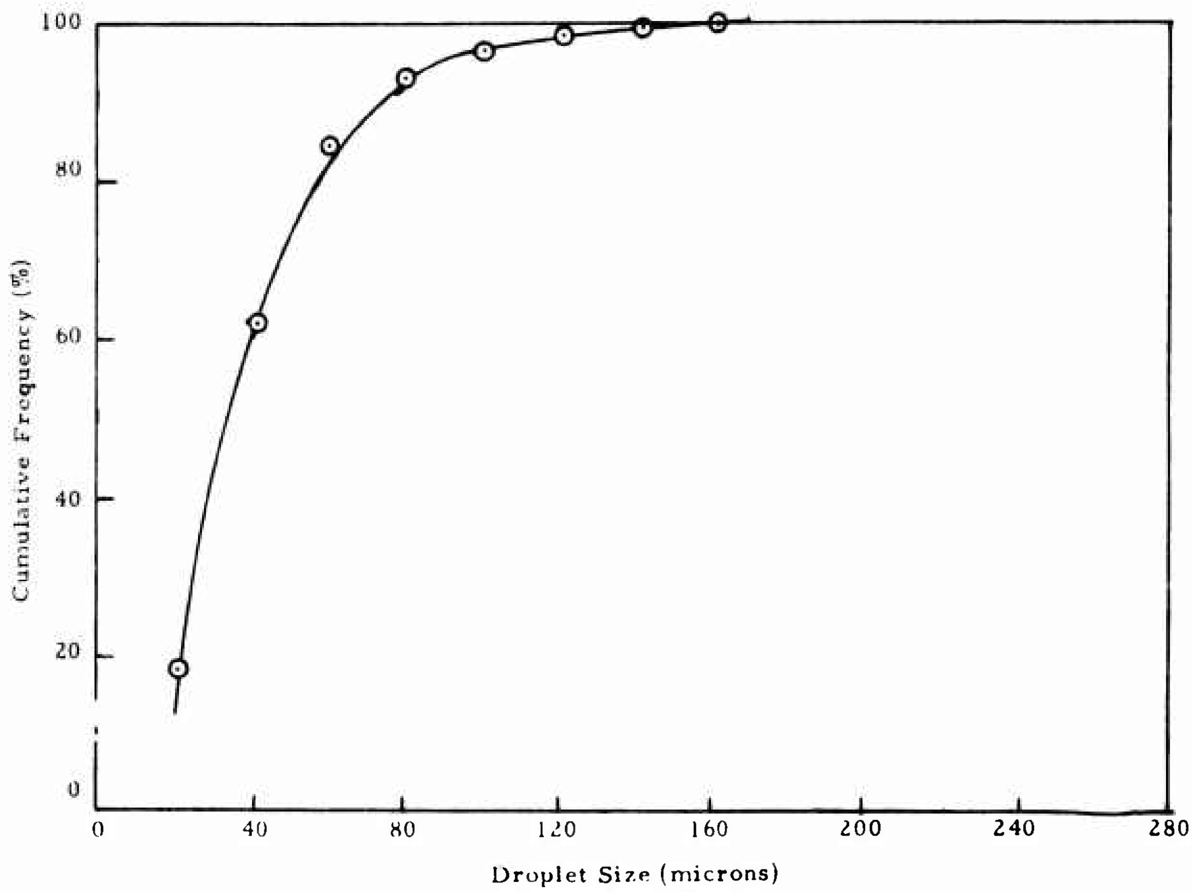

Figure 22. Droplet Size Distribution - Emulsified JP-4 - Simplex Orifice Nozzle (800 dynes/cm^2).

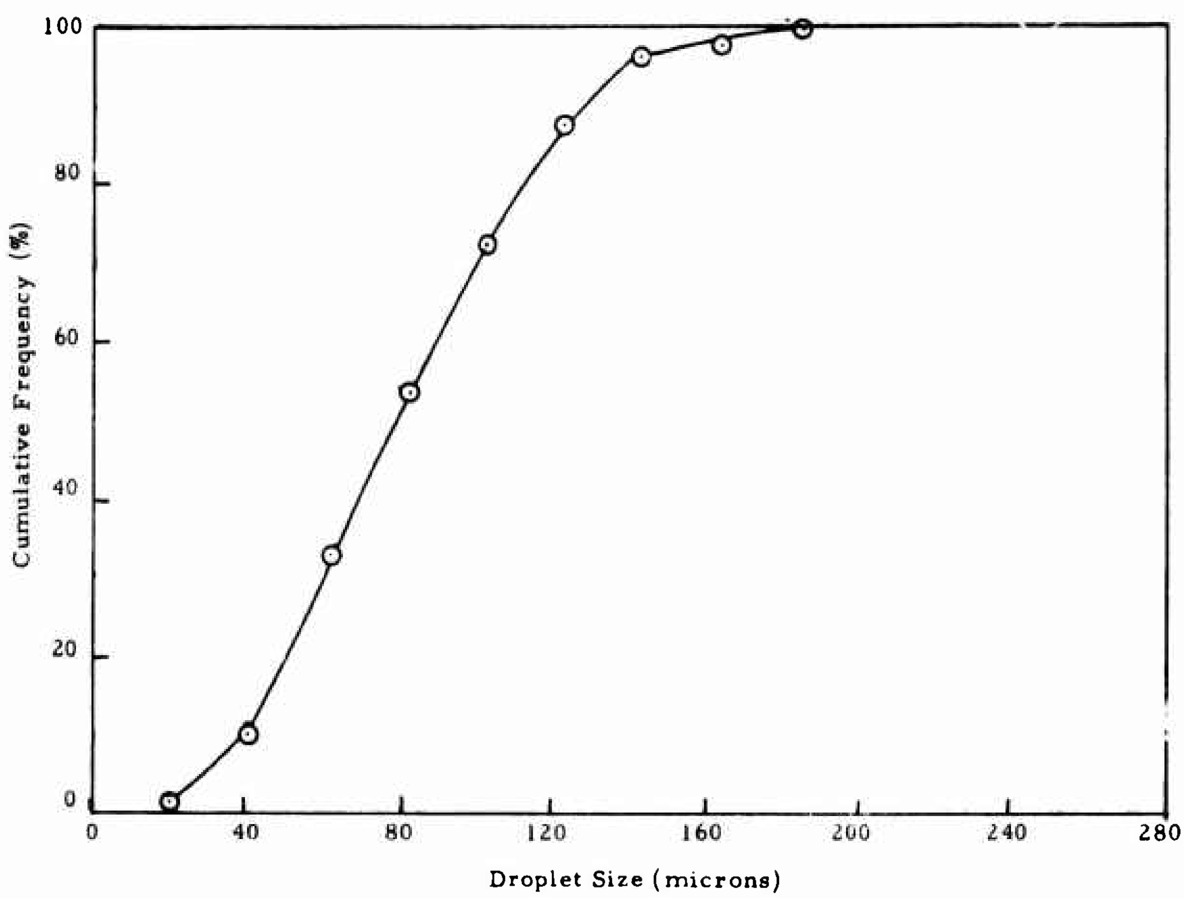

Figure 23. Droplet Size Distribution - Emulsified JP-4 Fuel ($2400\ dynes/cm^2$).

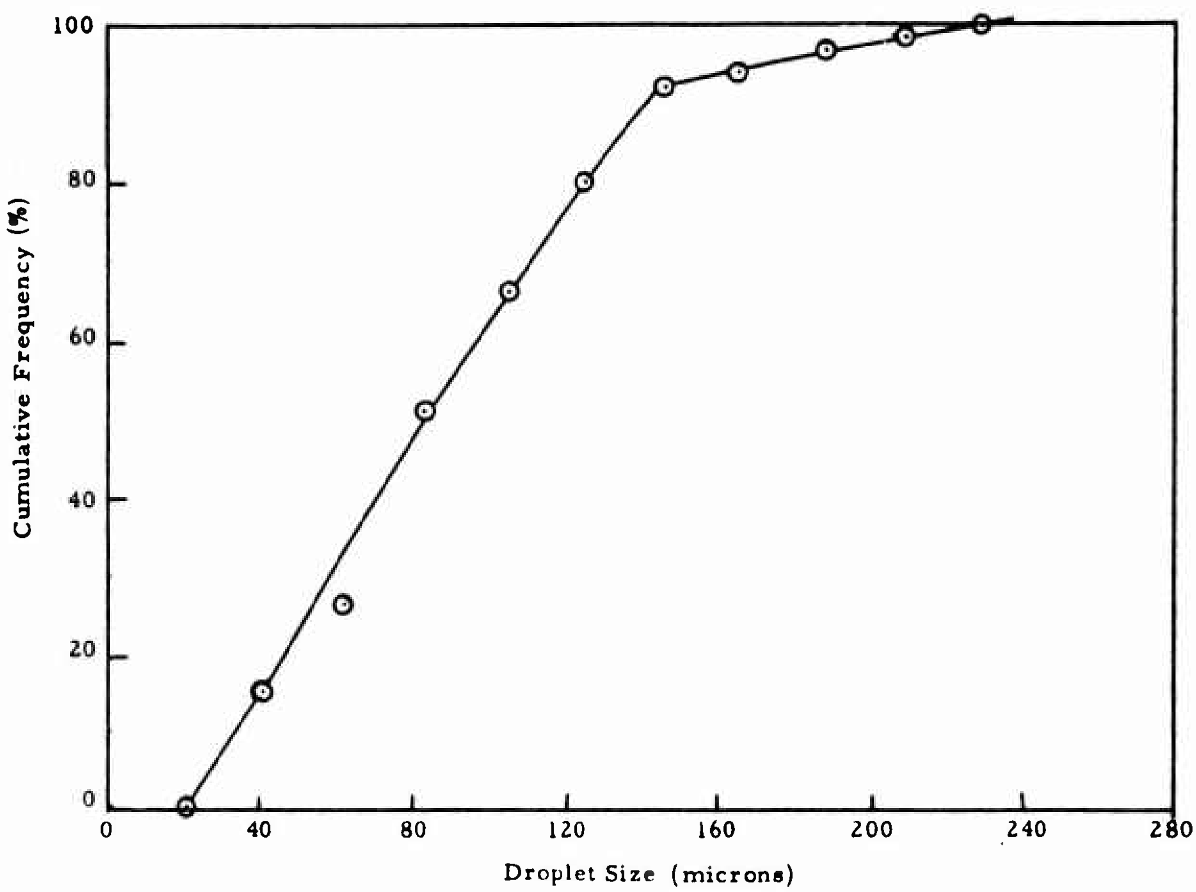

Figure 24. Droplet Size Distribution - Emulsified JP-4 Fuel (2400 dynes/cm^2).

Figure 25. Neat JP-4 Passing Through Simplex Orifice Nozzle (Actual Nozzle Diameter - 0.240 in.).

Figure 26. Emulsified JP-4 (800 dynes / cm^2) Passing Through Simplex Orifice Nozzle (Actual Nozzle Diameter - 0.240 in.).

Figure 27. Emulsified JP-4 (2400 dynes/cm^2) Passing Through Simplex Orifice Nozzle (Actual Nozzle Diameter - 0. 240.).

Figure 28. Emulsified JP-4 (2400 dynes/cm^2) Passing Through Simplex Orifice Nozzle (Actual Nozzle Diameter - 0.240 in.).

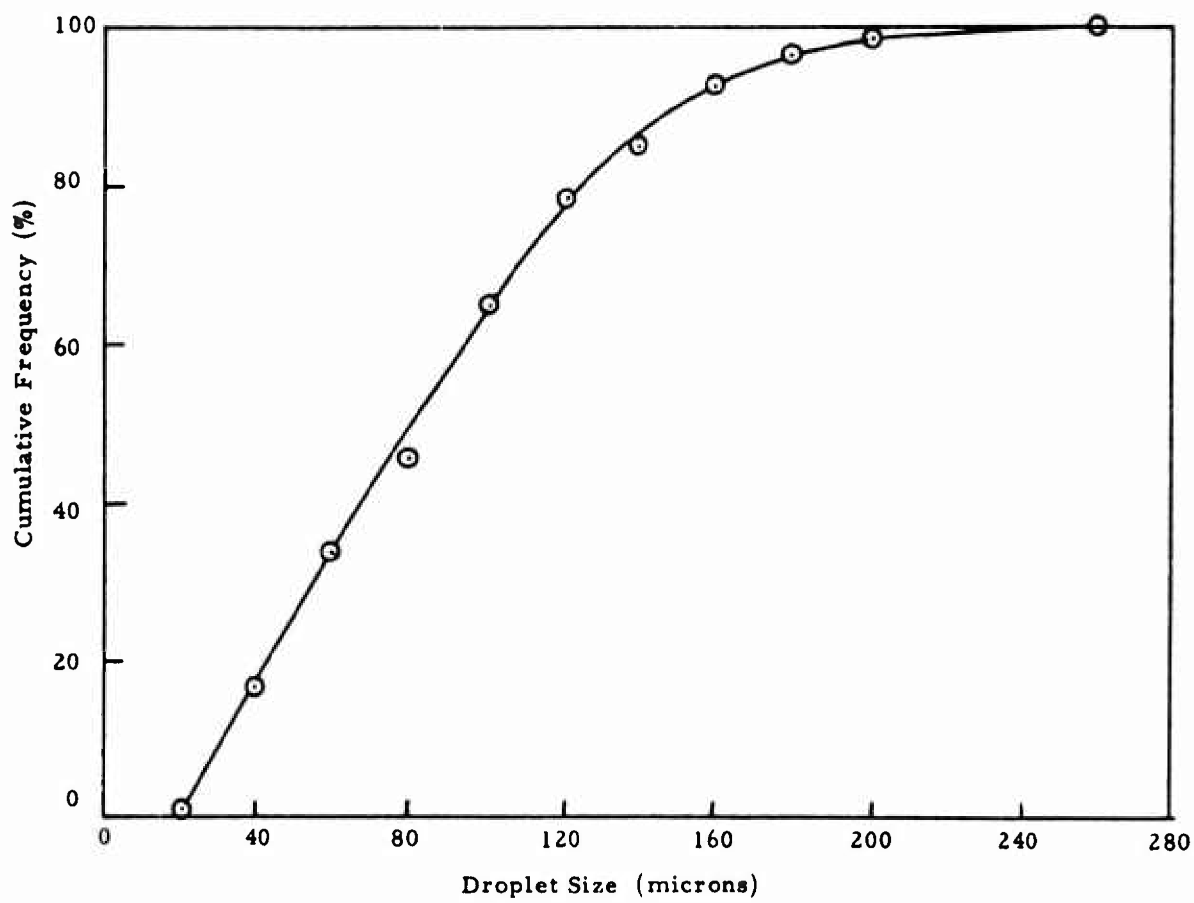

Figure 29. Droplet Size Distribution - Neat JP-4 - Dual Orifice Nozzle.

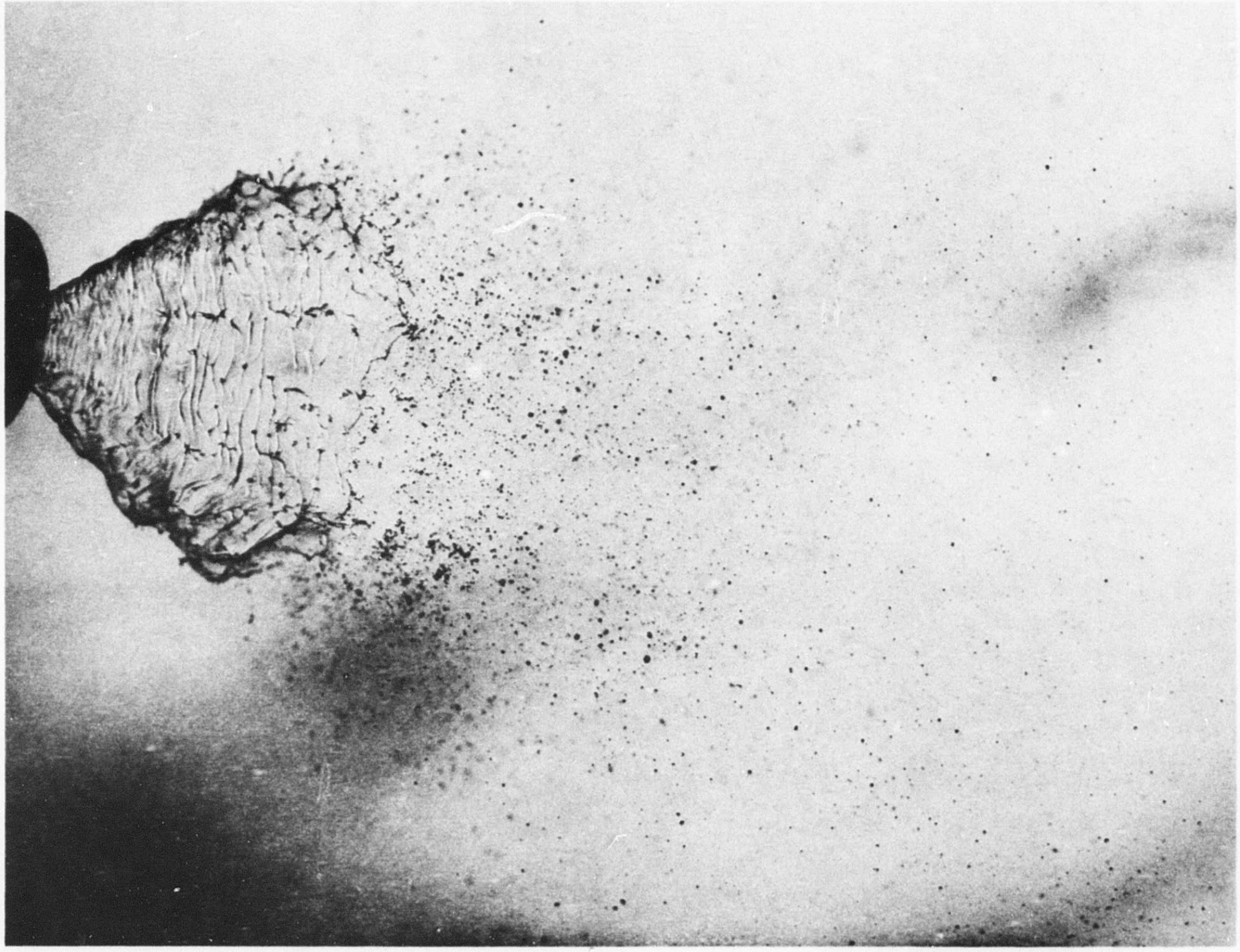

Figure 30. Neat JP-4 Passing Through Dual Orifice Nozzle (Actual Nozzle Size 0. 400 in.).

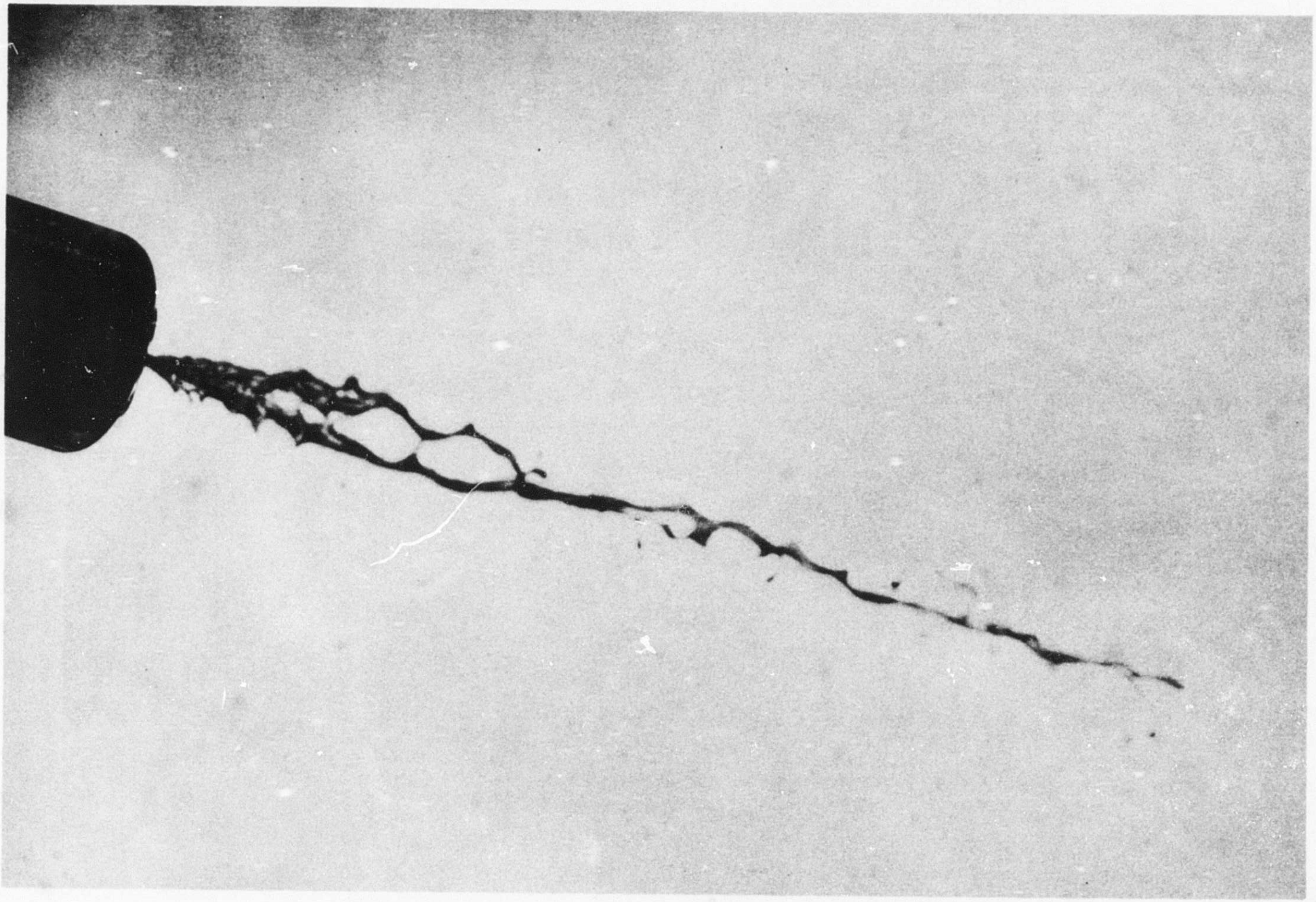

Figure 31. Emulsified JP-4 (800 dynes / cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0. 400 in.).

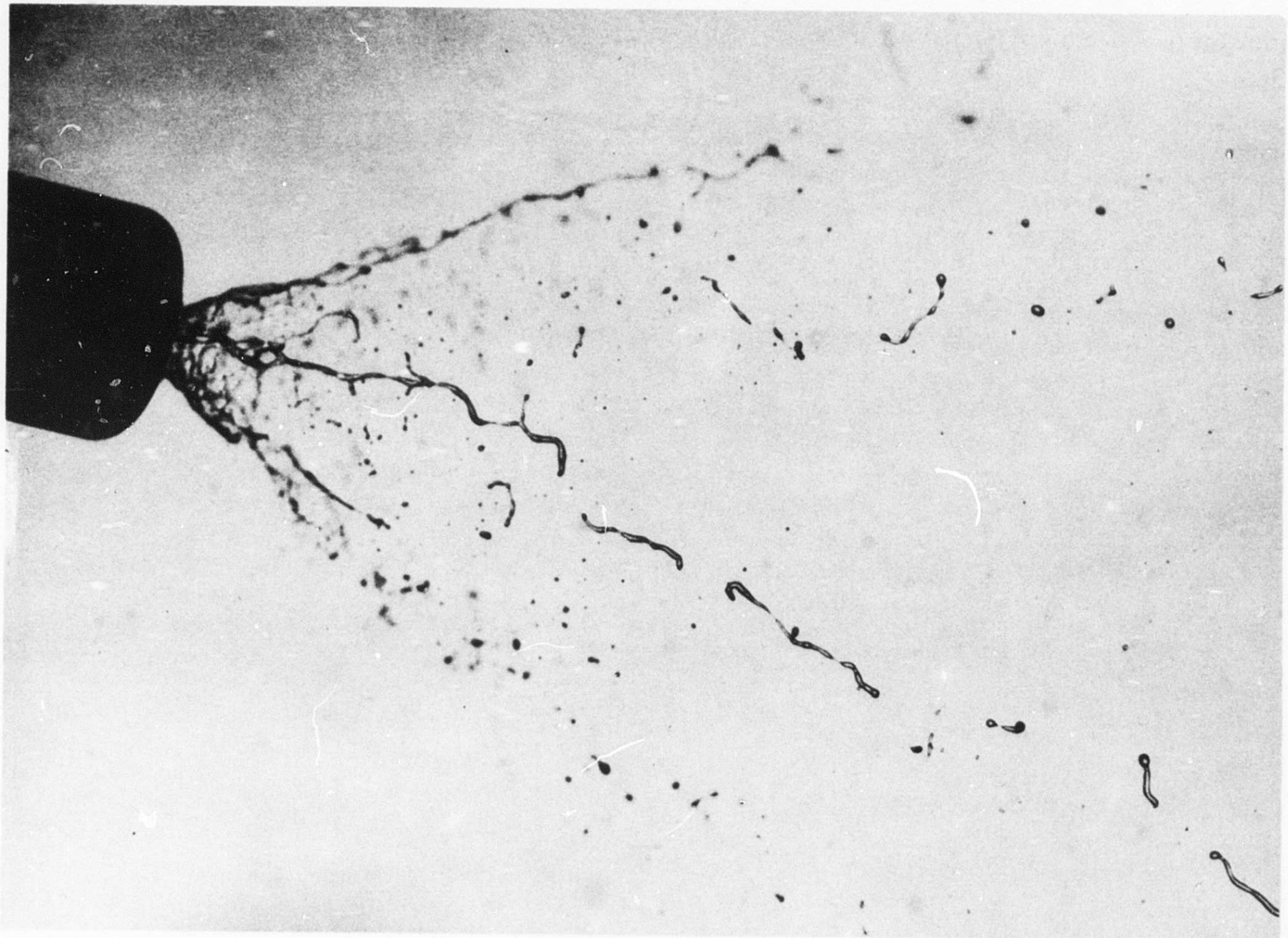

Figure 32. Emulsified JP-4 (800 dynes/cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0.400in.).

Figure 33. Emulsified JP-4 (800 dynes/cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0. 400 in.).

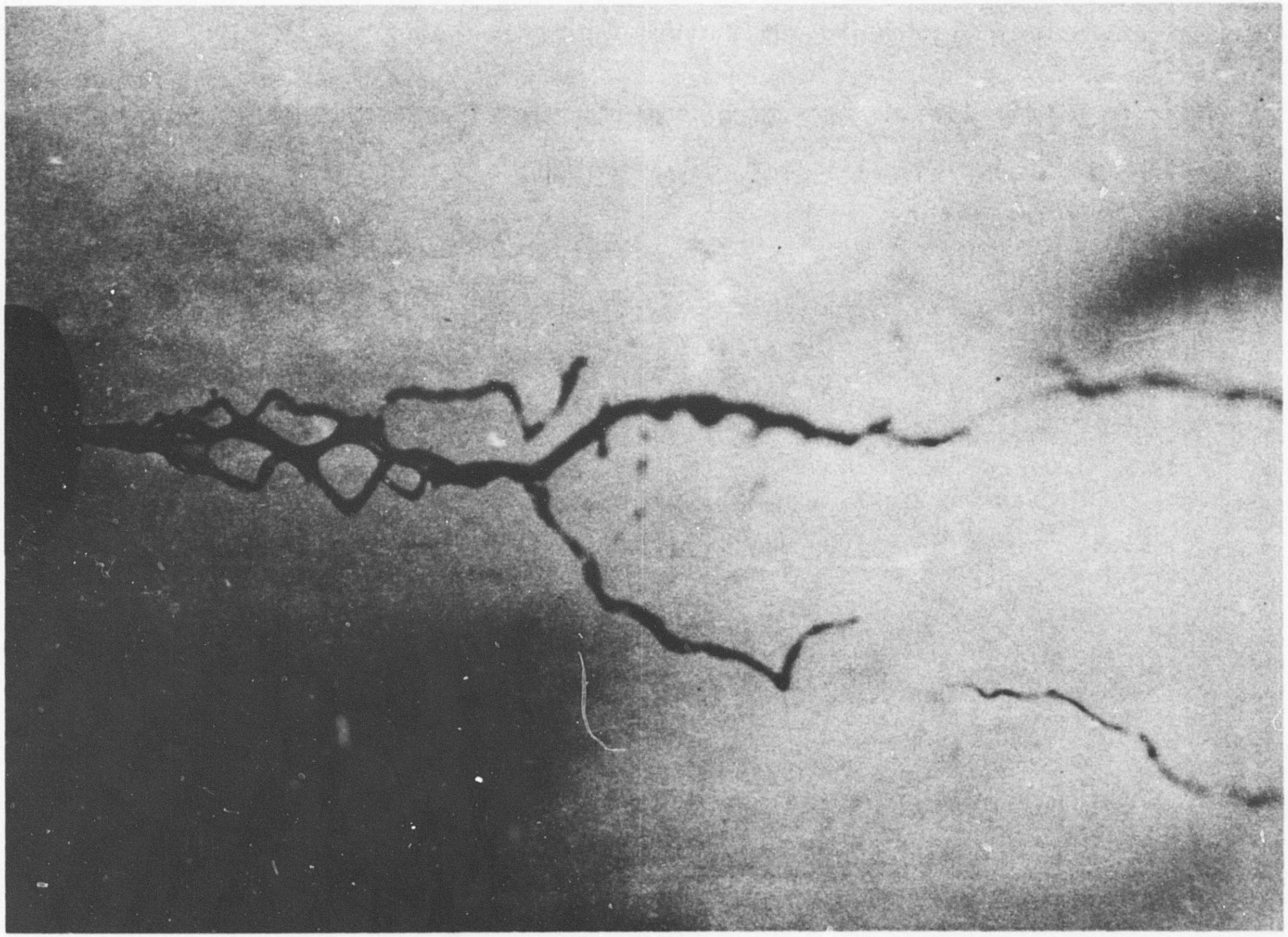

Figure 34. Emulsified JP-4 (2400 dynes/cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0.400 in.).

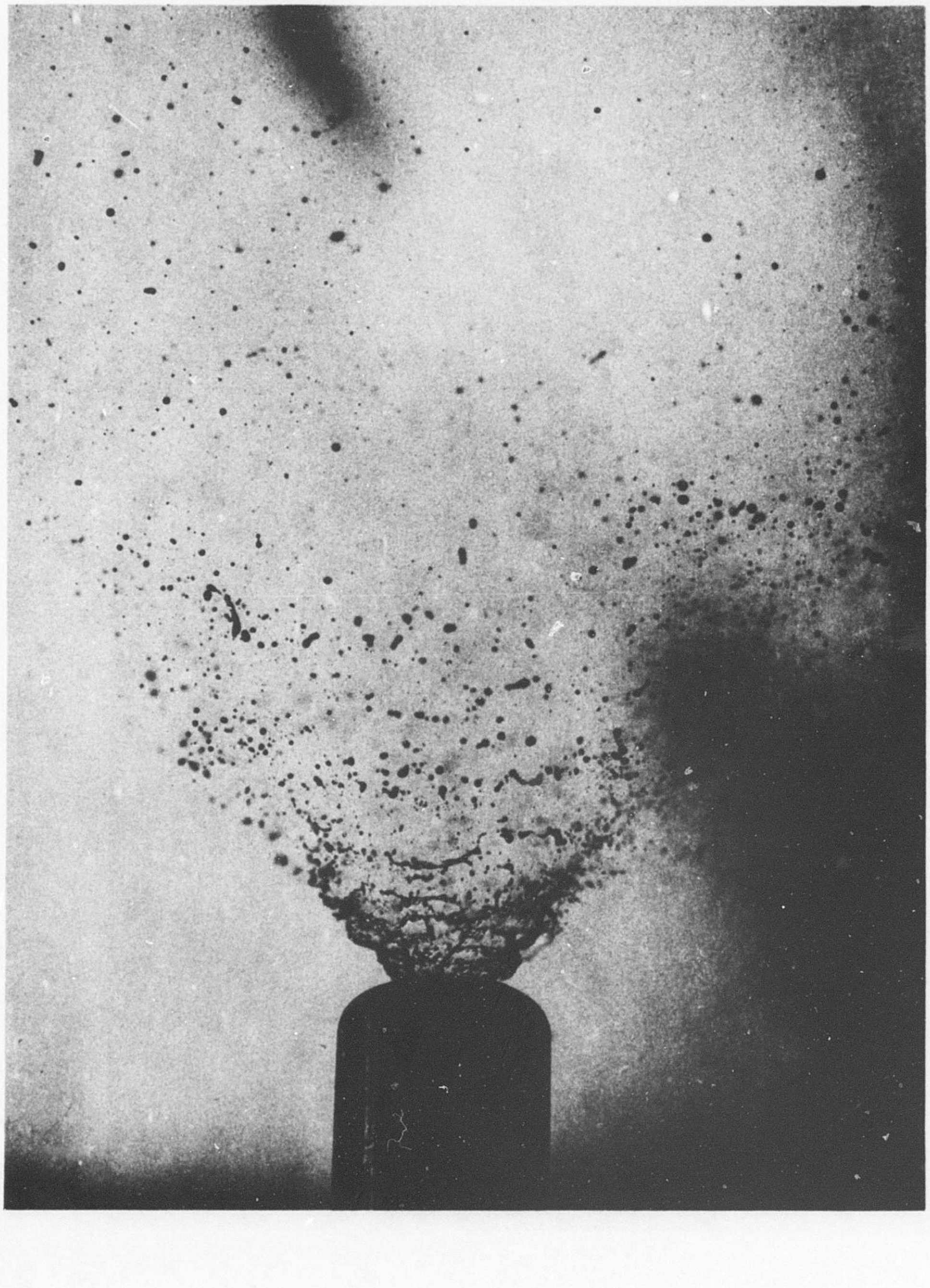

Figure 35. Emulsified JP-4 (2400 dynes/cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0. 400 in.).

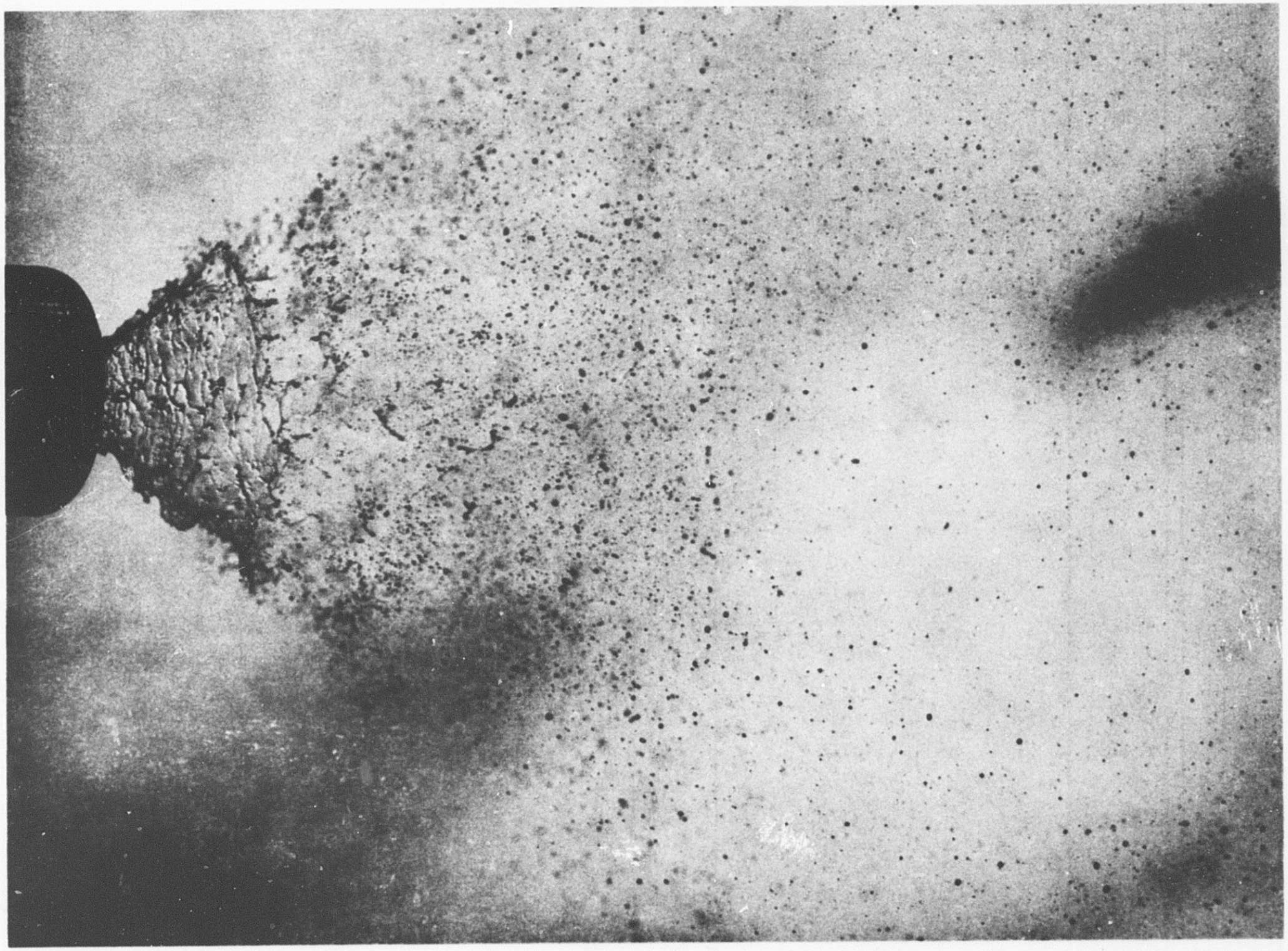

Figure 36. Emulsified JP-4 (2400 dynes/cm^2) Passing Through Dual Orifice Nozzle (Intermittent Behavior) (Actual Nozzle Size 0.400 in.).

TABLE I. EMULSIFIED JP-4 FUEL* YIELD POINT VS TEMPERATURE (RISING SPHERE METHOD)

Temp (°F)	Yield Point (dynes/cm^2)
- 20	7360
+ 10	2980
+ 40	2100
+ 77	905
+130	775

*Lot 7 - Drum 100

TABLE II. EMULSIFIED JP-4 FUEL* YIELD POINT VS MIXING TIME AND AGING (RISING SPHERE METHOD)

Mixing Time (min)	Yield Point Before Mixing (dynes/cm^2)	Yield Point (dynes/cm^2) After					
		0 Days	3 Days	6 Days	9 Days	12 Days	27 Days
3	1150	1600	1350	1350	1350	1280	1090
5	1150	2350	1050	1025	1050	965	890
10	1150	3600	1400	1425	1175	1070	915

*Lot 7 - Drum 100

TABLE III. EMULSIFIED JP-4 FUEL* - APPARENT VISCOSITY VS TEMPERATURE (CAPILLARY RHEOMETER)

Temp (°F)	Apparent Viscosity (poise) 10^3 sec^{-1}	10^4 sec^{-1}	10^5 sec^{-1}
- 20	1.7	0.5	0.3
+ 77	1.5	0.9	0.2
+130	-	0.6	0.2

*Lot 7 - Drum 100

TABLE IV. ALTERED EMULSIFIED JP-4 FUEL* - APPARENT VISCOSITY VS MIXING TIME AT 77°F (CONE AND PLATE VISCOMETER)

Mixing Time (min)	Yield Point (dynes/cm^2)	Apparent Viscosity (poise) 10^2 sec^{-1}	10^3 sec^{-1}	10^4 sec^{-1}	$\sim 2 \times 10^4$ sec^{-1}
0	1150	0.97	0.48	0.67	0.11
3	1600	1.57	0.75	0.56	0.11
5	2350	2.36	1.07	0.72	0.12
10	3600	2.10	0.92	0.65	0.07

*Lot 7 - Drum 100

TABLE V. EMULSIFIED JP-4 FUEL - DROPLET SIZE ANALYSIS OF AS-RECEIVED MATERIAL

NUMBER OF INPUTS 21

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
0.62	4.	0.0	0.74	0.74	2.46	0.93	0.58
0.74	9.	0.0	1.67	2.41	6.65	3.63	2.68
0.86	48.	0.0	8.89	11.30	41.38	30.75	26.51
0.99	59.	0.0	10.93	22.22	58.13	56.42	55.58
1.11	61.	0.0	11.30	33.52	67.61	83.05	92.05
1.23	104.	0.0	19.26	52.78	128.08	194.24	239.20
1.35	58.	0.0	10.74	63.52	78.57	144.18	195.32
1.49	40.	0.0	7.41	70.93	59.11	129.09	190.78
1.60	24.	0.0	4.44	75.[illegible]7	38.42	98.48	157.66
1.72	36.	0.0	6.67	82.[illegible]4	62.07	184.50	318.09
1.85	37.	0.0	6.85	88.89	68.35	233.23	430.83
1.97	29.	0.0	5.37	94.26	57.14	221.85	437.13
2.09	7.	0.0	1.30	95.56	14.65	64.23	134.47
2.22	5.	0.0	0.93	96.48	11.08	54.46	120.72
2.34	5.	0.0	0.93	97.41	11.70	64.05	149.87
2.46	7.	0.0	1.30	98.70	17.24	104.59	257.61
2.59	1.	0.0	0.19	98.89	2.59	17.30	44.73
2.71	3.	0.0	0.56	99.44	8.13	59.66	161.64
2.96	1.	0.0	0.19	99.63	2.96	25.82	76.31
3.08	1.	0.0	0.19	99.81	3.08	29.18	89.85
3.94	1.	0.0	0.19	100.00	3.94	61.20	[illegible]
TOTAL	540.	0.0	100.00		743.33	1860.85	3422.79

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.616 MICRONS
LARGEST PARENT PARTICLE 3.941 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 1.377 MICRONS
STANDARD DEVIATION 0.425 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 1.839 MICRONS

TABLE VI. EMULSIFIED JP-4 FUEL - DROPLET SIZE ANALYSIS AFTER SIX WEEKS STORAGE

6 WEEKS

NUMBER OF INPUTS 47

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)(D(I)3)	F(I)(D(I)4)
0.26	3.	0.0	0.40	0.40	0.78	0.05	0.01
0.35	5.	0.0	0.67	1.08	1.74	0.21	0.07
0.43	12.	0.0	1.61	2.69	5.21	0.98	0.43
0.52	20.	0.0	2.69	5.38	10.41	2.82	1.47
0.61	30.	0.0	4.03	9.41	18.22	6.72	4.00
0.69	54.	0.0	7.26	16.67	37.48	16.06	12.54
0.78	58.	0.0	7.80	24.46	45.29	27.62	21.57
0.87	47.	0.0	6.32	30.78	40.78	30.70	26.64
0.95	35.	0.0	4.70	35.48	33.41	30.43	29.05
1.04	35.	0.0	4.70	40.19	36.44	39.51	41.14
1.13	35.	0.0	4.70	44.89	39.48	50.23	56.67
1.21	26.	0.0	3.49	48.39	31.58	46.61	56.82
1.30	34.	0.0	4.57	52.96	44.25	74.97	97.57
1.39	26.	0.0	3.49	56.45	36.10	69.57	96.59
1.48	23.	0.0	3.09	59.54	33.93	73.82	108.89
1.56	15.	0.0	2.02	61.56	23.43	57.15	89.26
1.65	20.	0.0	2.69	64.25	32.97	89.62	147.75
1.74	29.	0.0	3.90	68.15	50.33	151.56	265.02
1.82	12.	0.0	1.61	69.76	21.87	72.60	132.29
1.91	21.	0.0	2.82	72.58	40.09	146.08	278.86
1.95	1.	0.0	0.13	72.71	1.95	7.44	14.53
2.00	21.	0.0	2.82	75.54	41.91	166.92	333.13
2.09	11.	0.0	1.48	77.02	22.91	99.34	206.88
2.17	25.	0.0	3.36	80.38	54.23	255.19	553.58
2.26	11.	0.0	1.45	81.85	24.82	126.31	284.95
2.34	15.	0.0	2.02	83.87	35.14	192.88	451.88
2.43	9.	0.0	1.21	85.08	21.87	129.07	313.58
2.52	9.	0.0	1.21	86.29	22.65	143.40	360.84
2.60	14.	0.0	1.88	88.17	36.44	246.95	642.82
2.69	15.	0.0	2.02	90.19	40.35	291.93	785.26
2.78	9.	0.0	1.21	91.40	24.99	192.66	534.96
2.86	7.	0.0	0.94	92.34	20.04	164.34	470.58
2.95	8.	0.0	1.09	93.41	23.60	205.42	606.01
3.04	7.	0.0	0.94	94.35	21.26	196.07	595.45
3.12	5.	0.0	0.67	95.03	15.62	152.40	476.06
3.21	5.	0.0	0.67	95.70	16.05	165.46	531.20
3.30	7.	0.0	0.94	96.64	23.08	250.93	827.39
3.38	4.	0.0	0.54	97.18	13.54	155.01	524.56
3.47	4.	0.0	0.54	97.71	13.88	167.24	580.47
3.64	5.	0.0	0.67	98.39	18.22	242.01	881.95
3.90	2.	0.0	0.27	98.66	7.81	119.06	464.90
3.99	1.	0.0	0.13	98.79	3.99	63.59	253.81
4.08	3.	0.0	0.40	99.19	12.23	203.48	829.83
4.16	2.	0.0	0.27	99.46	8.33	144.50	601.83
4.51	2.	0.0	0.27	99.73	9.02	183.72	828.94
5.12	1.	0.0	0.13	99.87	5.12	134.17	686.39
5.64	1.	0.0	0.13	100.00	5.64	179.41	1011.89
TOTAL	744.	0.0	100.00		1128.48	5568.23	16118.64

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.260 MICRONS
LARGEST PARENT PARTICLE 5.640 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 1.517 MICRONS
STANDARD DEVIATION 0.853 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 2.995 MICRONS

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TRACEBACK FOLLOWS- ROUTINE ISN REG. 14

IBCOM 4200042EC

MAIN 00003060

201814

TABLE VII. EMULSIFIED JP-4 FUEL - DROPLET SIZE ANALYSIS AFTER 12 WEEKS STORAGE

12 WEEKS

NUMBER OF INPUTS 32

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)D(I)	F(I)D(I)3	F(I)D(I)4
0.32	1.	0.0	0.84	0.84	0.32	0.03	0.01
0.37	3.	0.0	2.52	3.36	1.10	0.15	0.05
0.46	6.	0.0	5.04	8.40	2.74	0.57	0.26
0.50	3.	0.0	2.52	10.92	1.51	0.38	0.19
0.55	4.	0.0	3.36	14.29	2.19	0.66	0.36
0.59	1.	0.0	0.84	15.13	0.59	0.21	0.12
0.64	10.	0.0	8.40	23.53	6.40	2.62	1.67
0.69	18.	0.0	15.13	30.66	12.33	5.79	3.97
0.73	15.	0.0	12.61	51.26	10.96	5.86	4.28
0.78	6.	0.0	5.04	56.30	4.66	2.81	2.18
0.82	6.	0.0	5.04	61.34	4.93	3.34	2.74
0.87	1.	0.0	0.84	62.18	0.87	0.65	0.57
0.91	8.	0.0	6.72	68.91	7.31	6.10	5.57
0.96	2.	0.0	1.69	70.59	1.92	1.77	1.69
1.00	3.	0.0	2.52	73.11	3.01	3.04	3.06
1.05	1.	0.0	0.84	73.95	1.05	1.16	1.22
1.14	6.	0.0	5.04	78.99	6.85	8.94	10.21
1.19	4.	0.0	3.36	82.35	4.75	6.70	7.96
1.23	3.	0.0	2.52	84.87	3.70	5.63	6.94
1.28	2.	0.0	1.68	86.55	2.56	4.18	5.35
1.32	1.	0.0	0.84	87.39	1.32	2.32	3.08
1.37	2.	0.0	1.68	89.08	2.74	5.15	7.05
1.42	1.	0.0	0.84	89.92	1.42	2.84	4.02
1.51	2.	0.0	1.68	91.60	3.01	6.85	10.33
1.60	2.	0.0	1.68	93.28	3.20	8.17	13.07
1.83	2.	0.0	1.68	94.96	3.65	12.20	22.29
2.60	1.	0.0	0.84	95.80	2.60	17.65	45.96
2.65	1.	0.0	0.84	96.64	2.65	18.60	49.27
2.74	1.	0.0	0.84	97.48	2.74	20.59	56.43
2.92	1.	0.0	0.84	98.32	2.92	24.99	73.05
3.06	1.	0.0	0.84	99.16	3.06	28.67	87.74
3.20	1.	0.0	0.84	100.00	3.20	32.69	104.54
TOTAL	119.	0.0	100.00		112.28	241.31	535.26

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.320 MICRONS
LARGEST PARENT PARTICLE 3.198 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 0.944 MICRONS
STANDARD DEVIATION 0.537 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 2.218 MICRONS

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IBCOM 4200899C
MAIN 00003AE0

TABLE VIII. MEAN DROPLET DIAMETER VS STORAGE TIME				
Storage Time (weeks)	Fig. No.	Table No.	Mean Droplet Diameter (microns)	Standard Deviation (microns)
Original	10	V	1.4	0.4
6	11 - 12	VI	1.5	0.9
12	13	VII	0.9	0.5

TABLE IX. DROPLET SIZE ANALYSIS OF ALTERED EMULSIFIED JP-4 FUEL - 3 MINUTES MIXING TIME

THREE MIN.

NUMBER OF INPUTS 15

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
0.55	36.	0.0	6.86	6.86	19.63	5.84	3.19
0.65	42.	0.0	8.00	14.86	27.49	11.77	7.71
0.76	188.	0.0	35.81	50.67	143.55	83.69	63.90
0.87	150.	0.0	28.57	79.24	130.90	99.68	86.98
0.99	37.	0.0	7.05	86.29	36.32	35.01	34.37
1.09	58.	0.0	11.05	97.33	63.27	75.28	82.11
1.20	4.	0.0	0.76	98.10	4.80	6.91	8.29
1.31	2.	0.0	0.38	98.48	2.62	4.49	5.87
1.53	1.	0.0	0.19	98.67	1.53	3.56	5.44
1.64	1.	0.0	0.19	98.86	1.64	4.38	7.17
1.75	1.	0.0	0.19	99.05	1.75	5.32	9.28
1.85	1.	0.0	0.19	99.24	1.85	6.38	11.82
1.96	1.	0.0	0.19	99.43	1.96	7.57	14.86
2.18	1.	0.0	0.19	99.62	2.18	10.38	22.65
2.29	2.	0.0	0.38	100.00	4.58	24.04	55.07
TOTAL	525.	0.0	100.00		444.06	384.29	418.71

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.545 MICRONS
LARGEST PARENT PARTICLE 2.291 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 0.846 MICRONS
STANDARD DEVIATION 0.202 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 1.090 MICRONS

TABLE X. DROPLET SIZE ANALYSIS OF ALTERED EMULSIFIED JP-4 FUEL - 5 MINUTES MIXING TIME

5 MINUTES

NUMBER OF INPUTS 40

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)D(I)	F(I)D(I)3	F(I)D(I)4
0.05	2.	0.0	1.11	1.11	0.10	0.00	0.00
0.25	3.	0.0	1.67	2.78	0.75	0.05	0.01
0.30	3.	0.0	1.67	4.44	0.90	0.08	0.02
0.35	15.	0.0	8.33	12.78	5.28	0.65	0.23
0.40	10.	0.0	5.56	18.33	4.02	0.65	0.26
0.45	9.	0.0	5.00	23.33	4.07	0.83	0.38
0.50	23.	0.0	12.78	36.11	11.56	2.92	1.47
0.55	6.	0.0	3.33	39.44	3.32	1.01	0.56
0.60	11.	0.0	6.11	45.56	6.63	2.41	1.45
0.65	3.	0.0	1.67	47.22	1.96	0.84	0.55
0.70	11.	0.0	6.11	53.33	7.74	3.83	2.69
0.75	14.	0.0	7.78	61.11	10.55	6.00	4.52
0.80	10.	0.0	5.56	66.67	8.04	5.20	4.18
0.85	5.	0.0	2.78	69.44	4.27	3.12	2.66
0.90	5.	0.0	2.78	72.22	4.52	3.70	3.35
0.95	3.	0.0	1.67	73.89	2.86	2.61	2.49
1.00	4.	0.0	2.22	76.11	4.02	4.06	4.08
1.06	3.	0.0	1.67	77.78	3.17	3.53	3.72
1.11	3.	0.0	1.67	79.44	3.32	4.05	4.48
1.16	2.	0.0	1.11	80.56	2.31	3.09	3.57
1.21	3.	0.0	1.67	82.22	3.62	5.26	6.35
1.26	8.	0.0	4.44	86.67	10.05	15.86	19.92
1.31	1.	0.0	0.56	87.22	1.31	2.23	2.91
1.36	3.	0.0	1.67	88.89	4.07	7.49	10.17
1.41	1.	0.0	0.56	89.44	1.41	2.79	3.92
1.51	2.	0.0	1.11	90.56	3.01	6.85	10.33
1.61	1.	0.0	0.56	91.11	1.61	4.16	6.69
1.81	1.	0.0	0.56	91.67	1.81	5.92	10.71
2.01	1.	0.0	0.56	92.22	2.01	8.12	16.32
2.06	1.	0.0	0.56	92.78	2.06	8.74	18.02
2.16	1.	0.0	0.56	93.33	2.16	10.09	21.80
2.26	2.	0.0	1.11	94.44	4.52	23.12	52.29
2.36	1.	0.0	0.56	95.00	2.36	13.17	31.11
2.41	1.	0.0	0.56	95.56	2.41	14.03	33.85
2.71	1.	0.0	0.56	96.11	2.71	19.98	54.21
3.52	1.	0.0	0.56	96.67	3.52	43.52	153.09
3.62	1.	0.0	0.56	97.22	3.62	47.36	171.35
3.72	1.	0.0	0.56	97.78	3.72	51.42	191.19
3.77	2.	0.0	1.11	98.89	7.54	107.06	403.48
5.02	2.	0.0	1.11	100.00	10.05	253.77	1275.19
TOTAL	180.	0.0	100.00		162.96	699.57	2533.56

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.050 MICRONS
LARGEST PARENT PARTICLE 5.025 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 0.905 MICRONS
STANDARD DEVIATION 0.789 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 3.622 MICRONS

TABLE XI. DROPLET SIZE ANALYSIS OF ALTERED EMULSIFIED JP-4 FUEL - 10 MINUTES MIXING TIME

10 MINUTES

NUMBER OF INPUTS 13

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)(D(I)3)	F(I)(D(I)4)
0.43	4.	0.0	0.93	0.93	1.74	0.33	0.14
0.52	1.	0.0	0.23	1.17	0.52	0.14	0.07
0.61	36.	0.0	8.41	9.58	21.87	8.07	4.90
0.69	93.	0.0	21.73	31.31	64.56	31.11	21.59
0.78	41.	0.0	9.59	40.89	32.02	19.53	15.25
0.87	146.	0.0	34.11	75.00	126.68	95.38	82.76
0.95	34.	0.0	7.94	82.94	32.45	29.56	28.22
1.04	40.	0.0	9.35	92.29	41.65	45.16	47.02
1.13	6.	0.0	1.40	93.69	6.77	8.61	9.71
1.21	16.	0.0	3.74	97.43	19.44	28.68	34.84
1.30	5.	0.0	1.17	98.60	6.51	11.02	14.35
1.39	5.	0.0	1.17	99.77	6.94	13.38	18.57
1.74	1.	0.0	0.23	100.00	1.74	5.23	9.07
TOTAL	428.	0.0	100.00		362.87	296.19	286.50

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 0.434 MICRONS
LARGEST PARENT PARTICLE 1.735 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 0.848 MICRONS
STANDARD DEVIATION 0.175 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 0.967 MICRONS

TABLE XII. MEAN DROPLET DIAMETER VS MIXING TIME				
Mixing Time (minutes)	Fig. No.	Table No.	Mean Droplet Diameter (microns)	Standard Deviation (microns)
Original	10	V	1.4	0.4
3	17	IX	0.8	0.2
5	18	X	0.9	0.8
10	19	XI	0.8	0.2

TABLE XIII. AVERAGE CONSISTENCY OF EMULSION AT NOZZLE INLET AND OUTLET

Yield Point (dynes/cm^2)	Nozzle		Breakdown (percent bw liquid) Inlet	Outlet
800	Simplex		≈70	100
800	Dual	Primary	≈70	-
		Secondary	≈30	-
		Total	≈60	≈80
2400	Simplex		≈45	≈50
2400	Dual	Primary	≈45	-
		Secondary	Nil	-
		Total	≈35	≈30

TABLE XIV. SPRAY CHARACTERISTICS OF SIMPLEX NOZZLE

Fig. No.	Material	Spray Angle (degrees)	Sheet Length (inches)
25	JP-4	89	0.14
-	JP-4	100	0.15
26	Emulsified JP-4 (800 dynes/cm^2)	87	0.09
-	Emulsified JP-4 (800 dynes/cm^2)	87	0.16
-	Emulsified JP-4 (800 dynes/cm^2)	94	0.11
28	Emulsified JP-4 (2400 dynes/cm^2)	102	No sheet
-	Emulsified JP-4 (2400 dynes/cm^2)	87	0.13
27	Emulsified JP-4 (2400 dynes/cm^2)	101	0.05
-	Emulsified JP-4 (2400 dynes/cm^2)	91	0.12
-	Emulsified JP-4 (2400 dynes/cm^2)	91	Sheet indistinguishable

TABLE XV. DROPLET SIZE ANALYSIS - NEAT JP-4 - SIMPLEX ORIFICE NOZZLE

NOZ C

NUMBER OF INPUTS 7

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
16.05	15.	0.0	1.90	1.90	240.75	62017.62	995382.19
32.10	518.	0.0	65.74	57.64	16627.79	**********	***********
48.15	38.	0.0	4.82	72.46	1329.70	4242011.00	***********
64.20	155.	0.0	19.67	92.13	9951.00	**********	***********
96.30	48.	0.0	6.09	98.22	4622.40	**********	***********
128.40	12.	0.0	1.52	99.75	1540.80	**********	***********
160.50	2.	0.0	0.25	100.00	321.00	8269032.00	***********
TOTAL	788.	0.0	100.00		35133.42	**********	***********

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 16.050 MICRONS
LARGEST PARENT PARTICLE 160.500 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 44.586 MICRONS
STANDARD DEVIATION 22.322 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 87.094 MICRONS

TABLE XVI. DROPLET SIZE ANALYSIS - EMULSIFIED JP-4 (800 DYNES/CM²) SIMPLEX ORIFICE NOZZLE

NOZ D

NUMBER OF INPUTS 8

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)D(I)	F(I)D(I)3	F(I)D(I)4
20.20	83.	0.0	18.00	18.00	1676.40	684119.37	13819204.00
40.40	205.	0.0	44.47	62.47	8282.00	**********	***********
60.60	102.	0.0	22.13	84.60	6181.20	**********	***********
80.80	40.	0.0	8.68	93.28	3232.00	**********	***********
101.00	17.	0.0	3.69	96.96	1717.00	**********	***********
121.20	8.	0.0	1.74	98.70	969.60	**********	***********
141.40	3.	0.0	0.65	99.35	424.20	8481432.00	***********
161.60	3.	0.0	0.65	100.00	484.80	**********	***********
TOTAL	461.	0.0	100.00		22967.37	**********	***********

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 20.200 MICRONS
LARGEST PARENT PARTICLE 161.600 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 49.821 MICRONS
STANDARD DEVIATION 25.046 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 93.605 MICRONS

TABLE XVII. DROPLET SIZE ANALYSIS - EMULSIFIED JP-4 (2400 DYNES/CM²) SIMPLEX ORIFICE NOZZLE

SLIDE X

NUMBER OF INPUTS 9

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
20.50	2.	0.0	1.44	1.44	41.00	17230.25	353220.12
41.00	12.	0.0	8.63	10.07	492.00	827052.00	33909120.00
61.50	32.	0.0	23.02	33.09	1968.00	7443468.00	***********
82.00	29.	0.0	20.86	53.96	2378.00	**********	***********
102.50	26.	0.0	18.71	72.66	2665.00	**********	***********
123.00	21.	0.0	15.11	87.77	2583.00	**********	***********
143.50	12.	0.0	8.63	96.40	1722.00	**********	***********
164.00	2.	0.0	1.44	97.84	328.00	8821888.00	***********
184.50	3.	0.0	2.16	100.00	553.50	**********	***********
TOTAL	139.	0.0	100.00		12730.50	**********	***********

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 20.500 MICRONS
LARGEST PARENT PARTICLE 184.500 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 91.586 MICRONS
STANDARD DEVIATION 34.453 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 126.175 MICRONS

TABLE XVIII. DROPLET SIZE ANALYSIS - EMULSIFIED JP-4 (2400 DYNES/CM²) SIMPLEX ORIFICE NOZZLE

SLIDE V

NUMBER OF INPUTS 11

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
20.90	1.	0.0	0.76	0.76	20.90	9129.32	190802.56
41.80	19.	0.0	14.50	15.27	794.20	1387655.00	58004016.00
62.70	15.	0.0	11.45	26.72	940.50	3697374.00	***********
83.60	32.	0.0	24.43	51.15	2675.20	**********	***********
104.50	20.	0.0	15.27	66.41	2090.00	**********	***********
125.40	18.	0.0	13.74	80.15	2257.20	**********	***********
146.30	16.	0.0	12.21	92.37	2340.80	**********	***********
167.20	2.	0.0	1.53	93.89	334.40	9348422.00	***********
188.10	4.	0.0	3.05	96.95	752.40	**********	***********
209.00	2.	0.0	1.53	98.47	418.00	**********	***********
229.90	2.	0.0	1.53	100.00	459.80	**********	***********
TOTAL	131.	0.0	100.00		13083.38	**********	***********

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 20.900 MICRONS
LARGEST PARENT PARTICLE 229.900 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 99.873 MICRONS
STANDARD DEVIATION 43.157 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 151.810 MICRONS

TABLE XIX. SAUTER MEAN PARTICLE SIZE DIAMETER VS MATERIAL TYPE - DROPLET SIZE DISTRIBUTION FOR SIMPLEX ORIFICE NOZZLE

Material	Fig. No.	Table No.	Sauter Mean Droplet Diameter (microns)	Standard Deviation (microns)
Neat JP-4	25	XV	87	22
Emulsified JP-4 (800 dynes/cm^2)	26	XVI	93	25
Emulsified JP-4 (2400 dynes/cm^2)	27	XVII	126	34
Emulsified JP-4 (2400 dynes/cm^2)	28	XVIII	151	43

TABLE XX. SPRAY CHARACTERISTICS OF DUAL ORIFICE NOZZLE			
Fig. No.	Material	Spray Angle (degrees)	Sheet Length (inches)
30	JP-4	78.5	0.58
-	JP-4	64	0.64
-	Emulsified JP-4 (800 dynes/cm^2)	84.5	0.30
33	Emulsified JP-4 (800 dynes/cm^2)	76	0.43
31	Emulsified JP-4 (800 dynes/cm^2)	20	None
-	Emulsified JP-4 (800 dynes/cm^2)	75	0.30
-	Emulsified JP-4 (800 dynes/cm^2)	76	0.28
32	Emulsified JP-4 (800 dynes/cm^2)	51	Partial sheet 0.16
36	Emulsified JP-4 (2400 dynes/cm^2)	73	0.28
34	Emulsified JP-4 (2400 dynes/cm^2)	21.5	None
-	Emulsified JP-4 (2400 dynes/cm^2)	81	0.31
35	Emulsified JP-4 (2400 dynes/cm^2)	79	Partial 0.23

TABLE XXI. DROPLET SIZE ANALYSIS - NEAT JP-4 - DUAL ORIFICE NOZZLE

NUMBER OF INPUTS 11

MID PT. DIAMETER D(I)	TOTAL NO. OF PARENT PARTICLES F(I)	TOTAL NO. HAVING SATELLITES P(I)	F(I) IN RANGE % FREQUENCY	CUMULATIVE F(I) % FREQUENCY	F(I)(D(I))	F(I)D(I)3)	F(I)(D(I)4)
20.00	1.	0.0	0.53	0.53	20.00	8000.00	160000.00
40.00	30.	0.0	15.79	16.32	1200.00	1920000.00	76800000.00
60.00	33.	0.0	17.37	33.68	1980.00	7128000.00	***********
80.00	22.	0.0	11.58	45.26	1760.00	**********	***********
100.00	37.	0.0	19.47	64.74	3700.00	**********	***********
120.00	26.	0.0	13.68	78.42	3120.00	**********	***********
140.00	12.	0.0	6.32	84.74	1680.00	**********	***********
160.00	15.	0.0	7.89	92.63	2400.00	**********	***********
180.00	7.	0.0	3.69	96.32	1260.00	**********	***********
200.00	5.	0.0	2.63	98.95	1000.00	**********	***********
260.00	2.	0.0	1.05	100.00	520.00	**********	***********
TOTAL	190.	0.0	100.00		18640.00	**********	***********

% SATELLITE ATTACHMENT 0.0

SMALLEST PARENT PARTICLE 20.000 MICRONS
LARGEST PARENT PARTICLE 260.000 MICRONS

ARITHMETIC MEAN PARTICLE DIAMETER 98.105 MICRONS
STANDARD DEVIATION 46.164 MICRONS

WEIGHT MEAN PARTICLE DIAMETER 158.114 MICRONS

IHC217I

TRACEBACK FOLLOWS- ROUTINE ISN REG. 14

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13. ABSTRACT

A study has been made to characterize an emulsified JP-4 fuel which, if proven to be operational for jet engines, can greatly increase aircraft safety. The study includes the measurement of the rheological properties, namely, yield point and apparent viscosity, over a range of temperatures and as a function of mixing time and aging. The droplet diameter of the fuel before and after alteration (by additional mixing) and after aging was also established.

The results show that both the yield point and the apparent viscosity of the emulsion increase with decreasing temperature. The emulsion, if mixed for 2 to 5 minutes in a dough type mixer, will increase in yield point. However, there appears to be very little difference in the droplet diameter of batches having different yield points. The droplet diameter does not appear to be affected by aging. In addition, the pressure drop across a 20-foot length of 1-inch line was measured, and the spray pattern developed after flow through a helicopter nozzle was analyzed. The pressure drop was unaffected by the rheology of the emulsion, but the spray pattern through the fine orifice nozzles was adversely affected. Liquid JP-4 formed a stable fine-mist spray, while the emulsion formed a spray which ranged from good atomization to almost no atomization.

It was concluded from the above studies that the emulsion can be used over a wide temperature range (-10°to 140°F) but must be broken down to a liquid form before efficient atomization can be achieved.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Emulsified JP-4 Fuel						
Internal Phase Droplet Size						
JP-4 Fuel						
Nozzle Spray Pattern						
Rheology						
Spray Droplet Size						

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